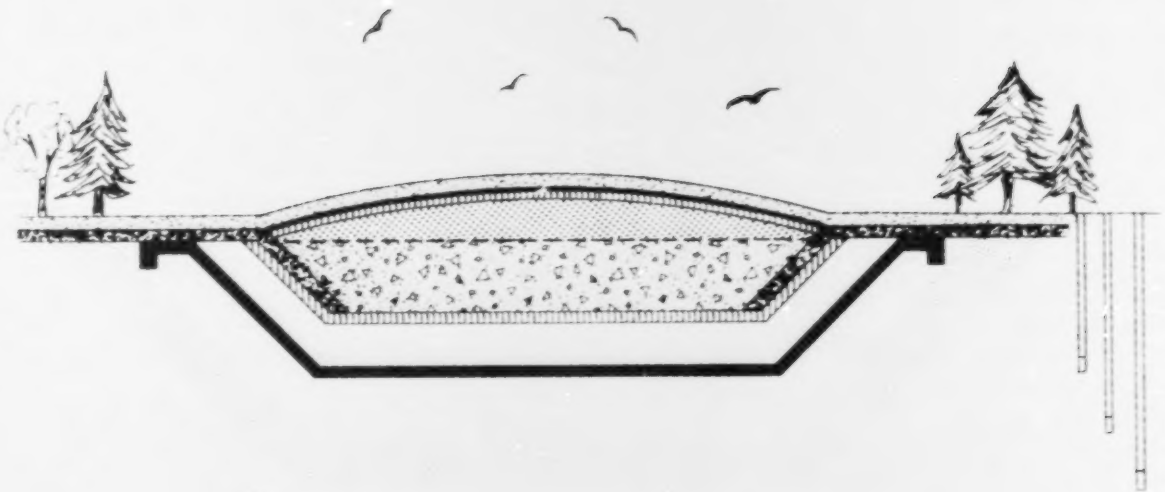
CCME

Canadian Council of Ministers of the Environment

Le Conseil canadien des ministres de l'environnement

National Guidelines for the Landfilling of Hazardous Waste

Report CCME-WM/TRE-028E
April 1991



Think Recycling!

Pensez à recycler!

This publication is printed on paper containing recovered waste.

91-04630/

National Guidelines for the Landfilling of Hazardous Waste

The Canadian Council of Ministers of the Environment

CCME-WM/TRE-28E
April 1991

CANADIAN CATALOGUING IN PUBLICATION DATA

Canadian Council of Ministers of the Environment

National guidelines for the landfilling of
hazardous waste

([Report] ; CCME-WM/TRE-28E)
Includes an abstract in French.
Includes bibliographical references.
ISBN 0-662-18735-0
DSS cat. no. En108-3/1-28E

1. Sanitary landfills -- Canada. 2. Hazardous waste sites -- Canada. 3. Environmental monitoring -- Canada. I. Title. II. Series: Report (Canadian Council of Ministers of the Environment) ; CCME-WM/TRE-28E.

TD795.7.C32 1991 628.4'4564 C91-098616-9

©Canadian Council of Ministers of the Environment 1991
Catalogue No. En108-3/1-28E
ISBN 0-662-18735-0
BEAUREGARD PRINTERS LIMITED

Readers' Comments

Readers who wish to comment on the contents of this report should address their comments to:

F. Laperrière
Waste Management Branch
Conservation and Protection
Environment Canada
Ottawa, Ontario
K1A 0H3

Ce rapport est aussi disponible en français sous le titre "Lignes directrices nationales sur l'enfouissement des déchets dangereux", à l'adresse ci-dessous.

For additional copies of this report, please contact your provincial environment ministry or write to:

CCME Secretariat
139 Tuxedo Avenue, Bldg. 30
Winnipeg, Manitoba
R3N 0H6

Abstract

This guideline document has been commissioned as part of the Canadian Council of Resource and Environment Ministers' Hazardous Waste Action Plan announced in March, 1987. The Action Plan calls for the drafting of National Guidelines for Hazardous Waste Incineration, Physical/Chemical/Biological Treatment, and Landfilling to ensure the protection of the natural environment and public health. This document sets forth the guidelines for the landfilling of hazardous wastes.

This document is also intended to provide a straightforward reference on the basic design, operating and performance standards to be used by the various federal and provincial regulatory agencies, designers, owners and operators of hazardous waste landfills in Canada. It is not intended to be a state-of-the-art technology review as this information can be obtained by reference to some of the many publications cited in the bibliography. It is also not intended to replace professional technical expertise in the various specialized disciplines involved in the field of hazardous waste landfilling.

Résumé

Le présent document a été rédigé dans le cadre du Plan d'action sur les déchets dangereux du Conseil canadien des ministres des Ressources et de l'Environnement, annoncé en mars 1987. Le Plan d'action prévoit l'établissement de directives nationales sur l'incinération, le traitement physico-chimique et l'enfouissement des déchets dangereux de manière à assurer la protection du milieu naturel et de l'hygiène publique. Ce document énonce les directives pour l'enfouissement des déchets dangereux.

Les organismes de réglementation fédéraux et provinciaux, les promoteurs, les propriétaires et les exploitants pourront se servir des directives en question pour arrêter des normes sur la conception, l'exploitation et le rendement des décharges servant à l'enfouissement des déchets dangereux au Canada. Le présent document ne vise pas à faire le point sur les techniques existantes puisqu'on peut trouver ce genre d'information dans certaines des nombreuses publications citées dans la bibliographie. Il n'a pas non plus pour but de se substituer aux compétences des professionnels spécialisés dans les diverses disciplines qui ont trait à l'enfouissement des déchets dangereux.

Table of Contents

Abstract v
Résumé vi
List of Figures ix
Acknowledgements x
Summary of Recommended Guidelines xi

Section 1
Introduction 1
1.1 Scope 1
1.2 Overview of an Integrated Hazardous Waste Management System 1
1.2.1 Overall System 1
1.2.2 The Landfill Component 3
1.3 Alternative Approaches to Developing Guidelines 5
1.3.1 Types of Standards 5
1.3.2 Approach Used in these Guidelines 6

Section 2
Wastes Acceptable for Disposal in a Hazardous Waste Landfill 8
2.1 Historical Aspects 8
2.2 Rationale for Determining Acceptability 8

Section 3
Site Selection, Design, and Construction 10
3.1 Site Selection 10
3.2 General Design Considerations 10
3.2.1 General Layout and Security 11
3.2.2 Buildings and Facilities 12
3.2.3 Stormwater Management 13
3.2.4 Alternative Landfill Concepts 14
3.2.5 Alternative Landfill Development Methods 14
3.2.6 Geotechnical Engineering Considerations 16
3.3 Natural Attenuation Concept 17
3.3.1 Premises 17
3.3.2 Siting 17
3.3.3 Leachate Control 17
3.3.4 Monitoring 17
3.3.5 Long-term Care 17
3.3.6 Compensating Features 17
3.3.7 Examples of Natural Attenuation Landfills 18
3.4 Engineered Containment Concept 19

3.4.1 Overview of Liner Systems and Leachate Control Concepts 19
3.4.2 Liner Materials 22
3.4.3 Leachate Control 25
3.4.4 Engineered Cover 26
3.4.5 Gas Venting 27

Section 4
Operation and Monitoring 28
4.1 Overview 28
4.2 Administrative Procedures 28
4.3 Placement of Wastes 29
4.4 Emergency Procedures 30
4.5 Personnel Programs 30
4.6 Environmental Monitoring Programs 31
4.6.1 Overview 31
4.6.2 Physical Movement 32
4.6.3 Leachate 32
4.6.4 Leakage 32
4.6.5 Groundwater 32
4.6.6 Air Emissions 33
4.6.7 General Inspection 33

Section 5
Closure and Post-closure 34
5.1 Overview 34
5.2 Closure 34
5.3 Post-closure Care 34
5.4 Preservation of Records 35
5.5 Liability 35

References 37

Bibliography 38

List of Figures

1 Schematic Diagram of an Overall Hazardous Waste Treatment and Disposal System 2

2 Schematic Diagram of Potential Adverse Effects Resulting from a Hazardous Waste Landfill 4

3 Landfill Concepts 15

4 Schematic Diagram of an EPA Double Liner System for a Hazardous Landfill - Alternate 1 20

5 Schematic Diagram of an EPA Double Liner System for a Hazardous Waste Landfill - Alternate 2 20

6 Schematic Profile of an EPA Composite Double Liner System for a Hazardous Waste Landfill 21

7 Cross-section of Impermeable Hazardous Waste Cell 23

8 Cross-section of Cell Cover for Impermeable Hazardous Waste Cell 23

9 Cross-section of Cell Side in Impermeable Hazardous Waste Cell 24

10 Cross-section of Cell Bottom in Impermeable Hazardous Waste Cell 24

Acknowledgements

The time and expertise of those who have helped in the formulation of this publication are gratefully acknowledged. Special thanks are due to T.W. Foote of Environment Canada who prepared the document with the assistance of Reid Crowther and Partners Limited and Golder Associates Incorporated. Contributions were provided by members of the Waste Committee of the Canadian Council of Ministers of the Environment (CCME).

Summary of Recommended Guidelines

The following summary represents a compilation of all guidelines discussed in the five sections of this document.

Section 1 - Introduction

For the implementation of a hazardous waste landfill project, an overall program should be developed. This program should address, as a minimum, all the issues raised in this guideline document while keeping project-specific circumstances in mind.

Section 2 - Wastes Acceptable for Disposal in a Hazardous Waste Landfill

(a) The following wastes generally should be prohibited from landfills:

- liquids and materials containing free liquids,
- empty containers unless they are crushed, shredded, or similarly reduced in volume, and
- explosives, flammable solids, spontaneously combustible materials, water-reactive materials, oxidizers and organic peroxides.

(b) Consideration should be given to the establishment of allowable levels of organic hazardous wastes, particularly halogenated organic compounds, which can be landfilled. Dilution or blending of hazardous wastes with other materials should not be allowed for the sole purpose of achieving the concentration limits specified in Guideline 2-2.

(c) Hazardous wastes should be treated/processed to the maximum possible extent which is consistent with the best available technology appropriate for the type of waste and landfill disposal operation.

Section 3 - Site Selection, Design, and Construction

(a) The site selection process for establishing a hazardous waste landfill must address geotechnical, land-use, biological, socio-economic, human and environmental factors. In addition, the process must be carried out in accordance with the environmental assessment requirements specified by the respective federal, provincial, or territorial government.

(b) A complete site assessment involving experts in geology, hydrogeology, and air quality is required. Part of the assessment will include the development of a contaminant transport model which must be undertaken to estimate the potential environmental impact of contaminants migrating from the site at specific locations of concern.

(c) The layout of a hazardous waste landfill site should give due consideration to the physical aspects of the site, the proposed landfill development plan and efficient traffic flow patterns. Part of this layout involves the creation of a buffer zone which should be provided around the perimeter of the site to act as a visual screen and noise barrier. The width of the buffer zone and the visual/noise attenuation features to be incorporated into it may vary from site to site according to adjacent land use and local regulations.

(d) A security system consisting of, as a minimum, a perimeter fence and appropriate signage should be provided. Additional security measures such as posting a guard and installing alarm systems may be required depending on site-specific circumstances.

(e) The buildings and facilities at a hazardous waste landfill site should include an administration building that contains offices, a lunchroom, a laboratory, and a segregated "dirty" and "clean" personnel washup area. Other facilities which should be provided include a weigh scale, vehicle wash facility and maintenance building. These provisions to contain hazardous materials on site in the proper areas should also be extended to prevent contaminated or potentially-contaminated materials from being inadvertently transported from the site by means of "tire-tracking".

(f) Any contaminated or potentially contaminated liquid wastes generated by activities at the hazardous waste landfill should be segregated and managed as a hazardous waste unless proven otherwise. Some potential sources of these contaminated liquids would include shower water and water used to wash vehicles working on the site.

(g) Run-on should be directed away from active hazardous waste landfills. All reasonable means should be taken to avoid run-off from active portions of a hazardous waste landfill site. If run-off occurs, it should be considered to be potentially contaminated, checked for quality and, if appropriate, managed as a hazardous waste.

(h) The choice of which landfill concept to implement (above-ground, shallow entombed, or conventional) will depend on a detailed consideration of site-specific physical and environmental conditions. Selection of the preferred concept should be made with due consideration of the landfill integrity and the extent to which the escape of contaminants from the landfill are to be controlled.

(i) The choice of which landfill development method (cell, trench or area) to employ should be made in light of site and project-specific factors. In general, the discrete cell method is more suited for the landfilling of smaller waste quantities, whereas the trench or area development methods are more suited to larger waste quantities. Appropriate geotechnical engineering principles should be applied to different aspects of the hazardous wastes landfill facility such as: the construction of dykes, cut slopes, landfill cells, roadways, and drainage structures.

(j) The specification of a preferred liner material, natural and/or synthetic, will depend on site-specific considerations and shall be based on demonstrated compatibility with the hazardous wastes to be landfilled. The liner material's resistance to deterioration or failure due to climate changes and stresses associated with liner installation and landfill operation must also be clearly demonstrated.

(k) A leachate monitoring, collection and removal system should be installed beneath an "engineered containment" hazardous waste landfill in order to control contaminant migration from the site. Furthermore, any leachate collected from a hazardous waste landfill should be deemed to be a hazardous waste and managed accordingly unless proven otherwise.

(l) A final cover system should be installed over each landfill cell with the objective of isolating the wastes, controlling infiltration and providing weather erosion protection appropriate for the site. The barrier layer of the cover system should be integrated securely into the landfill liner system at the perimeter of the landfill cells. In addition, the cover system should be of sufficient thickness to minimize any stresses due to seasonal freeze/thaw cycles. The cover and bottom liner of the landfill should be designed such that no buildup of fluid occurs in a landfill cell.

(m) From the anticipated characteristics of disposed wastes, the potential for gas production should be determined and an appropriate system for gas collection, treatment and release provided.

Section 4 - Operation and Monitoring

(a) A comprehensive facility-specific operating manual should be prepared for each hazardous waste landfill. This manual should be reviewed by all staff, and used as the primary reference document for the day-to-day operation of the facility.

(b) A comprehensive waste materials inventory control and record-keeping system should be established for the landfill site and rigorously adhered to by all operating personnel.

(c) A comprehensive vehicle and equipment maintenance manual should be prepared for all mobile and stationary equipment on the site and used as a basic equipment reference manual. The maintenance manual should include equipment decontamination and personnel protection measures.

(d) Care should be taken when operating equipment to ensure that the integrity of the landfill liner and leachate control system is not breached. Care should also be taken in equipment operation and maintenance to ensure that contaminated materials are not inadvertently "tracked" from the active areas of the landfill site. In this regard, equipment washwater and spent cleaning solutions should be collected separately and treated as a hazardous waste unless proven otherwise.

(e) An emergency procedures plan should be prepared for responding to all realistically foreseeable mishaps which could occur on the landfill site. The plan should be prepared in consultation with provincial and nearby community emergency response authorities. The emergency procedures plan should be reviewed and amended on a regular basis to reflect changes in personnel, technology, equipment and/or response procedures.

(f) All personnel at the landfill site should be given a comprehensive training program and subjected to pre-employment and regular post-hiring medical examinations.

(g) Prior to the establishment of a hazardous waste landfill facility, the proponent should prepare an environmental baseline profile of the proposed site and immediate surrounding area which will serve as the reference point for subsequent monitoring efforts.

(h) The owner or operator of a hazardous waste landfill facility should be required to implement an environmental monitoring program for both operational and post-closure periods with regard to: physical movement, leachate, leakage, groundwater and air emissions. Furthermore, comprehensive historical records should be maintained of all monitoring data collected

for the pre-operational, operational, and post-closure stages of the site.

(i) Prior to commencing operation, consideration should be given to the establishment of a set of conditions which, as indicated by monitoring results, signify failure and trigger implementation of remedial action as called for in the emergency procedures plan.

Section 5 - Closure and Post-closure

(a) Closure and post-closure care plans for a hazardous waste landfill site should be prepared as part of the initial planning and design phase for the overall facility. In addition, they should be updated if they are in any way affected by changes in facility design or operating procedures during the active life of the landfill. The owner or operator of a hazardous waste landfill site should be required to close the facility in a manner that:

- minimizes the need for further maintenance, and
- controls the post-closure escape of hazardous contaminants to the groundwater, surface water and atmosphere to the extent necessary to protect human health and the environment.

(b) When closure is completed, all equipment and facilities used at the site, with the exception of monitoring facilities and equipment, should be decontaminated or disposed of in an appropriate manner. The site itself will also be subject to restricted use. Land use restrictions for the completed site should be defined and maintained indefinitely.

(c) The post-closure care plan should provide a description of activities which will be conducted after final closure of the site and the frequency of these activities. As a minimum, these activities should include:

- maintaining the function and integrity of the final cover,
- maintaining, monitoring, and operating the leachate and gas collection, removal, and treatment systems if installed,
- protection and maintenance of survey benchmarks, and
- control of access to the site in accordance with its approved post-closure use.

(d) A central repository for "as-built" drawings and other operational records should be established and maintained indefinitely by the provincial regulatory agency responsible for regulating the post-closure activities of landfill sites. In addition, this repository should maintain files dealing with on-going monitoring programs. Consideration should be given to entrenching the long-term maintenance of records in the form of legislation.

(e) Prior to commencing operation, some form of contingency financing should be provided in the event that the integrity of the landfill is breached and repairs are required either during its active life or following closure. The amount of financing required will depend on the size of the landfill, the types of wastes placed therein and pertinent site-specific factors. As a reference for establishing an amount, a current record should be kept of the costs of remedial measures at hazardous waste landfill sites across North America.

(f) To ensure the continuity of post-closure care and to eliminate the potential for another party unknowingly acquiring this responsibility, the hazardous waste landfill site should be legally registered on the appropriate deed or land title prior to commencing operation.

Section 1

Introduction

1.1 Scope

This document presents national guidelines for the landfilling of hazardous wastes for the use of regulatory agencies and hazardous waste management system designers, owners and operators. It provides general guidance for dealing with the many issues of concern that relate to the landfilling of hazardous wastes. The topics considered by the guidelines include:

- site selection,
- design and construction,
- closure and post-closure care, and
- operation and monitoring.

The guidelines are intended primarily for application to new landfill facilities, not existing ones. Furthermore, the guidelines are not directed toward the landfilling of radioactive wastes as regulated by the Atomic Energy Control Board. The guidelines provide a framework of principles, methodologies and minimum standards which, if adhered to, will minimize the risks to human health and to the environment posed by the landfilling of hazardous wastes. It is intended that the use of these guidelines will result in a more uniform national approach to the landfilling of hazardous wastes.

Given the variability of climatic and geological settings across Canada and the rapidly evolving nature of landfilling technology, it is recognized that a certain degree of flexibility must be afforded in the application of these guidelines. If it can be demonstrated that alternative approaches could be employed which ensure an acceptable level of protection for the environment and human health, such approaches should be deemed to be in compliance with the intent of this document.

1.2 Overview of an Integrated Hazardous Waste Management System

Before considering guidelines for the landfilling of hazardous wastes, it is useful to describe how a landfill fits into the various components of an integrated hazardous waste management system.

1.2.1 Overall System

Since hazardous wastes can retain their harmful properties over a very long period of time, perhaps for centuries, it is important to minimize the amount of hazardous waste requiring disposal. This can be achieved by implementing measures either to reduce the quantity of hazardous wastes produced, or to recover, recycle or otherwise reuse the wastes. If disposal is the only alternative, it is important to treat the wastes before disposal to render them less hazardous. This treatment may be achieved by means of thermal destruction or physical/chemical/biological means. The third significant step in hazardous waste disposal involves the disposal of the residues from the treatment and destruction process. This is usually accomplished by landfilling.

Figure 1 presents a simplified diagram of the steps involved in a "cradle to grave" system for the treatment and disposal of hazardous wastes. It illustrates that as many as five stages are possible in the overall waste management system. These include:

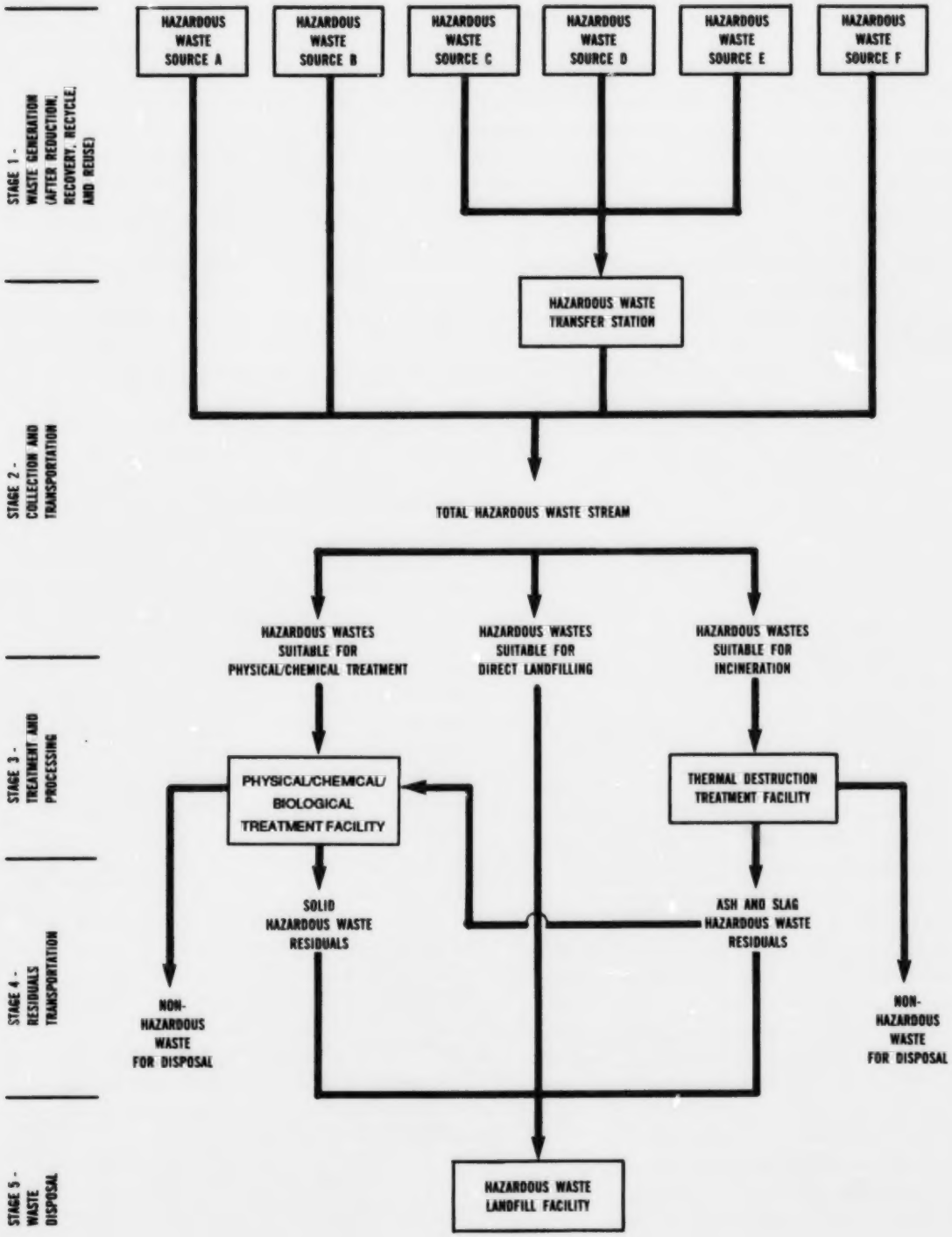

STAGE 1 - WASTE GENERATION (AFTER REDUCTION, RECOVERY, RECYCLE, AND REUSE)
HAZARDOUS WASTE SOURCE A
HAZARDOUS WASTE SOURCE B
HAZARDOUS WASTE SOURCE C
HAZARDOUS WASTE SOURCE D
HAZARDOUS WASTE SOURCE E
HAZARDOUS WASTE SOURCE F
HAZARDOUS WASTE TRANSFER STATION
STAGE 2 - COLLECTION AND TRANSPORTATION
TOTAL HAZARDOUS WASTE STREAM
HAZARDOUS WASTES SUITABLE FOR PHYSICAL/CHEMICAL TREATMENT
HAZARDOUS WASTES SUITABLE FOR DIRECT LANDFILLING
HAZARDOUS WASTES SUITABLE FOR INCINERATION
STAGE 3 - TREATMENT AND PROCESSING
PHYSICAL/CHEMICAL/ BIOLOGICAL TREATMENT FACILITY
THERMAL DESTRUCTION TREATMENT FACILITY
SOLID HAZARDOUS WASTE RESIDUALS
ASH AND SLAG HAZARDOUS WASTE RESIDUALS
STAGE 4 - RESIDUALS TRANSPORTATION
NON-HAZARDOUS WASTE FOR DISPOSAL
NON-HAZARDOUS WASTE FOR DISPOSAL
STAGE 5 - WASTE DISPOSAL
HAZARDOUS WASTE LANDFILL FACILITY

Figure 1 **Schematic Diagram of an Overall Hazardous Waste Treatment and Disposal System**

Stage 1 - Waste Generation:

This stage represents the actual production and on-site storage of hazardous wastes. The fraction of the wastes that is not suitable for reduction, recovery, recycling or reuse will require some means of proper treatment and disposal in subsequent stages.

Stage 2 - Waste Collection and Transportation:

This stage includes the collection of hazardous waste generated in Stage 1 and its transportation to the processing and disposal facilities used in the subsequent stages. Figure 1 illustrates the possibility of incorporating transfer stations as potential cost-effective measures for the collection of hazardous wastes generated in a specific geographic region to a central processing/disposal facility.

Stage 3 - Waste Processing:

In this stage, the waste is processed to reduce its volume, and to stabilize, minimize or eliminate its hazardous properties, and generally make it suitable for final disposal. The treatment steps could involve various combinations of physical, chemical, biological and thermal processes used either alone or in combination according to the type of waste being processed. Products of these processes will include treated atmospheric and aqueous effluent emissions, along with solid residuals that are detoxified, inert or otherwise stabilized.

Stage 4 - Residue Transportation:

The solid residues from Stage 3 are transported to the final point of disposition.

Stage 5 - Waste Disposal:

Residuals that are not discharged as treated effluents or emissions to the environment and which are still hazardous are deposited in a hazardous waste landfill.

A number of possibilities exist regarding the location of the various facilities that constitute an overall hazardous waste management system. A very large industrial complex may choose to have all five stages located on its own property. Alternately, the hazardous waste treatment facility, and the landfill facilities can be located together or on separate sites.

1.2.2 The Landfill Component

This guideline document is concerned primarily with Stage 5, the waste disposal portion of the overall hazardous waste management system. More specifically, it deals with the landfill disposal of the hazardous waste residuals from the various treatment processes.

Figure 2, illustrates the potential sources of adverse environmental effects that may arise from a hazardous waste landfill.

These potential sources are:

- gaseous emissions to the atmosphere due to gases and/or vapours that may evolve from the wastes deposited in the landfill,
- dust emissions to the atmosphere due to wind entrainment of fine particles of the waste deposited in the landfill,
- migration of materials off-site transported inadvertently on vehicles, on worker's clothing, etc.,
- direct exposure to the material deposited on the site through a breach in the security system,
- industrial hygiene and occupational concerns regarding exposure of workers

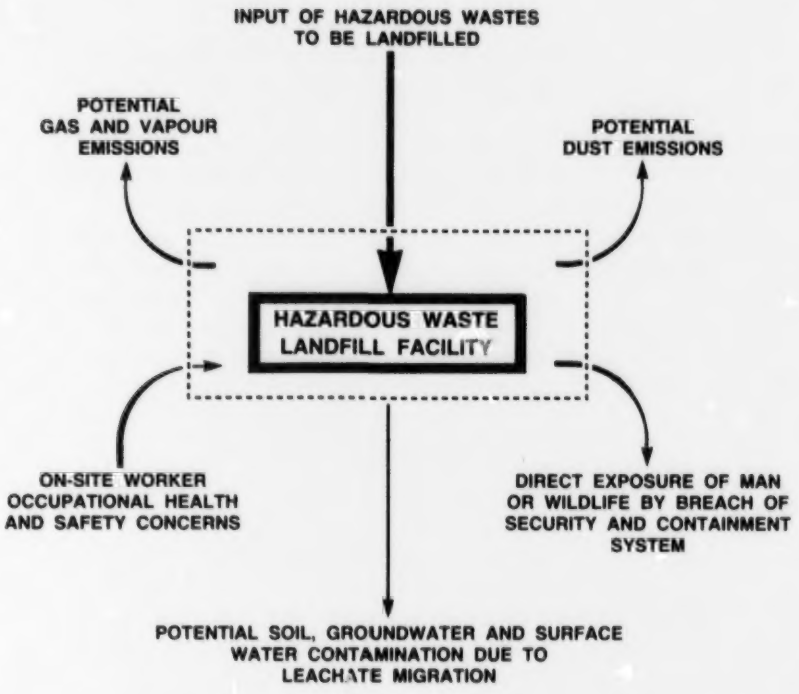


Figure 2 **Schematic Diagram of Potential Adverse Effects Resulting from a Hazardous Waste Landfill**

in the landfill to the waste materials being deposited therein, and

- soil, groundwater and surface water contamination due to leachate migration from the disposal site.

The design, operation, and closure of a hazardous waste landfill must address the short and long-term impact of the landfill on human health and the environment. As such, both the potential for discharge and pathways of possible discharge should be minimized during site selection, design, operation, and closure. Monitoring of potential pathways that may affect the environment should be carried out during the operation, closure, and post-closure period.

The general parameters that will reduce the potential effects on the environment include:

- site selection in an appropriate hydrogeologic setting,
- control of the material placed in the landfill,
- engineered systems to enhance containment and leak detection, and
- long-term monitoring of potential release pathways.

Site selection in a hydrogeologically appropriate environment is key to the long-term performance of a hazardous waste landfill. The site selection should provide reasonable assurances that releases during operation or during the post closure period will not result in traumatic deterioration of the pathway systems that could adversely affect human health and the environment. A discussion of the constraints to site selection is contained in Section 2 of the guidelines.

Control of material placed in the landfill includes reducing the quantity of leachate generation and minimizing the hazardous nature of the leachate. The quantity of

leachate can be reduced, for example, by controlling the amount of free liquids placed in a landfill. The hazardous nature of the waste can be reduced by setting treatment standards for materials that are of concern. A discussion of these issues is contained in Section 3 of the guidelines.

Engineered systems are measures that are adopted for landfill design, operation, and closure that enhance the containment of the hazardous waste and leachate. These systems include a leachate collection system, soil, and man-made liner materials, leak detection systems, and cover systems. It is emphasized that engineered controls should only be considered in conjunction with an appropriate hydrogeologic environment since it is possible that these systems will deteriorate before the waste loses its toxicity. Some engineered systems, such as a final cover, will be incorporated into all hazardous waste landfills. Engineered systems are addressed in Section 4 of the guidelines.

Long-term monitoring of potential release pathways provides assurance that the landfill can provide the required degree of protection to human health and the environment. The two most common monitoring requirements are final cover integrity and the effect on groundwater. Long-term monitoring guidelines are discussed in Section 5.

1.3 Alternative Approaches to Developing Guidelines

1.3.1 Types of Standards

In developing national guidelines for the disposal of treated hazardous wastes by landfilling, it is necessary to consider the types of standards that may apply to different aspects of landfill design, construction, operation, and closure. Such standards may be divided into three general categories as follows:

- **Landfill design and operating standards** - require the incorporation of specific equipment, design features, and procedures, into the operation of the facility,
- **Performance standards** - require a certain minimal level of performance from the facility, and
- **Risk assessment standards** - require that the facility not exceed the prescribed level of risk to human health and the environment.

An example of landfill **design and operating standards** would be a requirement to incorporate a specific liner material of a given thickness and permeability into the landfill design. Such an approach to establishing standards or guidelines offers a number of advantages including:

- the standards or guidelines are relatively straightforward and easily understood,
- guidelines can be utilized readily by both the owners, designers and regulators, for their own purpose, and
- they are relatively easy to interpret and enforce.

However, design and operating standards have been subject to considerable critical comment. Some of the more significant criticisms are:

- they discourage technical innovation and the development and application of new technology,
- they are inflexible and make no allowance for the possibility that different standards may be more appropriate for one set of circumstances than for another, and
- when applied retroactively to existing facilities that are operating well, they may result in a situation where it is not economically feasible to comply.

Performance standards can be divided into a number of categories as follows:

- Technical performance standards - which specify that the facility must satisfy certain requirements. An example would be a requirement to handle all stormwater without mishap for a specified storm intensity and return period,

- Containment performance standards - which specify that a certain level of containment must be achieved by the facility. An example would be that the landfill must contain a specified amount of the waste materials that are deposited therein for a specified period of time, and

- Environmental performance standards - which specify a maximum allowable contaminant level in the ambient environment around the landfill. An example of this standard would be specifications that the contaminant concentration in the groundwater at a particular point must not exceed a predetermined level.

Performance standards overcome the disadvantages of design and operating standards in that they allow the application of new and innovative technology. However, the application of performance standards has been criticized since these standards will require revision in light of new toxicological information that may be developed in the future.

In the **risk assessment** approach, standards are developed which are based on the degree of hazard at a facility and the corresponding risk to human health and the environment. The standards usually take the form of criteria that specify a certain maximum level of risk. Sometimes it is possible to quantify risk in absolute numbers using probabilities. Usually however, the data base is not adequate to establish absolute values. This means that broad narrative criteria must be formulated in order to compare alternative proposals and select a preferred option that poses the least risk. The risk assessment approach has been employed to establish acceptable contaminant levels in effluent discharges and in ambient water, air and soil. It has not been used to establish guidelines for the design, construction and operation of hazardous waste management facilities.

1.3.2 Approach Used in these Guidelines

There are a number of considerations that should be made in the development and application of national guidelines for the landfilling of hazardous wastes in Canada. They are:

- With respect to siting, these guidelines are specifically directed toward the establishment of hazardous waste landfill facilities. Should a landfill be established in conjunction with either physical/chemical/ biological treatment or thermal destruction facilities, some of the guidelines presented herein may not be totally appropriate.

- The climate, geography, geology, hydrogeology, ecology, population and land use varies markedly in the various regions of the country; in fact, the variability of these features among different areas of the same province can be extremely broad.

- The primary regulatory responsibility for the treatment and disposal of hazardous wastes lies with the provincial jurisdictions in Canada.

- Technologies for the treatment and disposal of hazardous wastes are being modified and improved continually.

It is reasonable to assume, therefore, that the establishment of any hazardous waste landfill facilities in Canada will be an undertaking unique to the area. The landfill site will require a customized approach to address specific project conditions. Therefore, the approach to developing guidelines for landfilling treated hazardous wastes in Canada should provide for flexibility of application so that the project-specific needs

are addressed. Certain general design and operating standards of the landfill will be essential, such as the need for a spill control and emergency response program. The primary reliance on performance standards will provide the owners, designers and regulators of hazardous waste management facilities with a degree of flexibility that permits innovation and adaptation of the design, construction and operation of the facility to suit the specific project. Given the complexity and lack of experience in employing the risk assessment approach for establishing hazardous waste management facilities, it is not considered appropriate at this time for use in this guideline document.

Guideline 1-1:

For the implementation of a hazardous waste landfill project, an overall program should be developed that addresses, as a minimum, all the issues raised in this guideline document. At the same time, flexibility should be maintained by adapting the guidelines to project-specific circumstances.

Section 2

Wastes Acceptable for Disposal in a Hazardous Waste Landfill

2.1 Historical Aspects

In the past, considerable quantities of untreated and treated liquid and solid hazardous wastes have been disposed of by landfilling. This practice has lead to numerous problems in the vicinity of old disposal sites, primarily due to contamination of groundwater and subsequent migration of the groundwater from the site. Costs associated with cleanup measures at contaminated sites can be extremely high. Consequently, a number of recent regulatory initiatives in several jurisdictions have been developed to ban the landfill disposal of certain materials.

2.2 Rationale for Determining Acceptability

There is concern over the long-term integrity, reliability and operability of liner systems, leachate control systems, and other engineered components of a landfill facility. Both clay and synthetic liners can be damaged during placement of the wastes. In addition, the properties of clay and synthetic liners can be altered by contact with certain wastes such as solvents. Thus, it is essential that landfill design and waste materials be compatible. For example, halogenated organic compounds in concentrations exceeding 1000 mg/kg have been prohibited from hazardous waste landfill in some jurisdictions.

Liquids placed in a landfill can contribute significantly to leachate generation. To minimize this generation, it is recommended that liquids and materials containing free liquids be excluded from landfills unless provision is made for their treatment within the landfill. This prohibition should be extended to include liquids adsorbed in materials. At the pressures that could exist in the depths of a landfill, liquids could be "squeezed out" of the absorbent material to become free liquids once again. Free liquids can be defined by the Paint Filter Liquids Test (U.S. Environmental Protection Agency, 1985).

Empty containers such as drums, boxes, and canisters should not be placed in landfills unless crushed, shredded, or processed by some other means to reduce their volume. This will eliminate the chance of subsidence occurring in the completed landfill due to collapse of the containers under the pressures experienced after burial. If subsidence were to occur, it could threaten the integrity of the landfill cover which would then require on-going maintenance to ensure the security of the landfill.

In order to protect the health of landfill workers and nearby residents, certain wastes exhibiting properties similar to those defined by the following regulations under the Transport of Dangerous Goods Act (Canada, 1985) should be banned from hazardous landfill sites:

- Transportation of Dangerous Goods Regulations Class I - Explosives (July 1985),
- Transportation of Dangerous Goods Regulations Class IV - Flammable Solids, Substances Liable to Spontaneous Combustion and Substances That on Contact with Water Emit Flammable Gases (July 1985), and
- Transportation of Dangerous Goods Regulations Class V - Oxidizing

Substances and Organic Peroxides (July 1985).

Such materials can create chemically unstable conditions if buried in a landfill.

Dilution or blending of a hazardous waste with a nonhazardous material should not be permitted for the sole purpose of diluting it to meet any specified concentration limit.

Guideline 2-1:

The following wastes should be generally prohibited from landfills:

- **liquids and materials containing free liquids,**
- **empty containers unless they are crushed, shredded or similarly reduced in volume, and**
- **explosives, flammable solids, spontaneously combustible materials, water-reactive materials, oxidizers and organic peroxides.**

Guideline 2-2:

Consideration should be given to the establishment of allowable levels of organic hazardous wastes, particularly halogenated organic compounds, which can be landfilled.

Guideline 2-3:

Dilution or blending of hazardous wastes with other materials should not be allowed for the sole purpose of achieving the concentration limits developed pursuant to Guideline 2-2.

Hazardous wastes to be deposited in a landfill should receive treatment and/or processing consistent with best demonstrated available technology appropriate to the type of waste. The objective in applying such technology should be to minimize the potential release of contaminants to the environment if the security of the landfill system is breached. The appropriate management methods and treatment/processing technology that can be applied to hazardous wastes prior to landfilling could include:

- reduction in waste volumes produced at the source by installing modifications to the industrial process producing the waste,
- recycling, recovery and/or reuse of various components of the waste,
- physical/chemical treatment for liquids-solids separation and detoxification,
- biological treatment for removal of biodegradable organic components,
- solidification/stabilization/fixation for converting liquid wastes to solid form and for encapsulating hazardous components, and
- thermal treatment for destruction of organic wastes.

Guideline 2-4:

Hazardous wastes should be treated with the best available technology which is appropriate for the type of waste and landfill disposal operation.

Section 3

Site Selection, Design, and Construction

3.1 Site Selection

It is a widely held assumption that public opposition to waste management facilities has become the most critical problem facing the waste management industry. This opposition is most frequently associated with the well-known NIMBY (not in my back yard) and LULU (locally unwanted land use) syndromes. Therefore in order that the site selection process proceed to its final stages, three key activities must take place:

- there must be disclosure of intentions to local citizens and other interested members of the public,
- there must be appropriate examination of potentially suitable sites, and
- there must be thorough investigation of candidate locations.

There is a need to approach site selection in terms of two essential considerations: technical criteria and community acceptability. Accordingly, public participation should be an integral part of project management from the outset. Program planning, for hazardous landfill sites should be conducted so that input from local sources and all data are made accessible and understandable to the general public. It is also important to note that decision making in this process must reflect public input.

The fundamental considerations in a hazardous waste management system design and site selection should be the safety of people and the protection of the environment. The approach to the site selection process should reflect these issues. Selection of a site that minimizes the potential for adverse community and environmental impacts greatly facilitates the implementation of a hazardous waste landfill.

Since the requirements of the environmental assessment process vary according to individual jurisdictions within Canada, it is recommended that the appropriate federal, provincial or territorial government agency be contacted for more specific information regarding the siting of hazardous waste management facilities.

Guideline 3-1:

The site selection process for establishing a hazardous waste landfill must address geotechnical, land-use, biological, socio-economic, human and environmental factors. This process must also be carried out in accordance with the environmental assessment requirements specified by the respective federal, provincial and territorial government.

3.2 General Design Considerations

A hazardous waste landfill must be designed and constructed so that it becomes the final repository for the waste materials. At the same time, the landfill must control any release of contaminants into the surrounding environment that could degrade its quality to a point that would impair the ongoing use of lands near the facility.

Conceptually, there are two basic approaches to the safe landfilling of hazardous waste: "natural attenuation" and "engineered containment". In the first approach, landfills designed to receive hazardous wastes are located only in areas where contaminant attenuation in the environment can be achieved naturally. This approach allows the possibility of achieving a condition where

maintenance is not required over the long term. The major disadvantage in the natural attenuation approach is that it is based largely upon the accuracy of predictions about the level of protection provided by the natural environment. Natural attenuation also requires the presence of suitable hydrological and geological conditions.

In the second approach, reliance is placed on engineered facilities rather than on natural attenuation to protect the environment. Typically, landfills designed using this approach combine engineered liners, covers, leachate and/or gas collection and treatment systems to control the release of contaminants to the environment.

While engineered containment reduces the potential risk associated with contaminant migration into the environment, questions remain concerning the integrity and functionality of such systems over the long term. The additional cost and responsibility associated with the maintenance and operation of such systems have to be accounted for. In practice, a specific landfill design may incorporate features from both basic design approaches to achieve the necessary level of environmental protection.

Regardless of the approach taken to landfill design, it is of paramount importance to have accurate information on the geological and hydrogeological characteristics of the site and the surrounding environment. Specific attention should be given to the development of a contaminant transport model to assist in estimating potential off-site environmental effects.

Guideline 3-2:

A complete site assessment (e.g., geology, hydrogeology, air quality, etc.), including development of a contaminant transport model, should be conducted to estimate the potential environmental impact of contaminants migrating from the site at specific locations of concern such as site boundaries and monitoring installations.

3.2.1 General Layout and Security

The layout of the site must take into account such matters as topography, the landfill development plan, road access from off-site, on-site traffic flow patterns, and aesthetic requirements such as visual screening and buffer zones.

The landfill development plan should provide for the progressive opening, filling and closing of areas on the site. All site closures should be conducted in a logical manner consistent with efficient and economic utilization of the site and protection of human health and the environment.

Access to the site should be strictly controlled. The general public should not have access to a hazardous waste landfill site as is sometimes the case with municipal landfills. Both incoming and outgoing traffic should pass through a single control point for manifest verification, sampling and any other regulatory and administrative actions. Appropriate signage, signals and lighting should be used to direct the flow of traffic on the site.

A suitable buffer zone should be provided around the perimeter of the site. The buffer zone could incorporate berms and/or trees planted to serve as a visual screen and noise barrier. It will also serve as a margin of safety for neighbours in the event of an accidental release of contaminants. The width of the buffer zone and the visual/noise attenuation features to be incorporated into it may vary according to adjacent land use.

The security of the site should be maintained by a perimeter fence to keep out unauthorized people as well as itinerant wildlife. The fence should be posted with signs to identify the site and warn trespassers to stay away. A telephone number to contact in case of emergency should also be posted. Consideration should also be given to posting

a security guard at the site and installing alarms on the gate and security fence.

Guideline 3-3:

The layout of a hazardous waste landfill site should give due consideration to the physical aspects of the site, the proposed landfill development plan and efficient traffic flow patterns.

Guideline 3-4:

A buffer zone should be provided around the perimeter of the site to act as a visual screen and noise barrier. The width of the buffer zone and the visual/noise attenuation features to be incorporated into it may vary according to land use and local regulations.

Guideline 3-5:

A minimum security system consisting of a perimeter fence and appropriate signage should be provided. Additional security measures such as posting a guard and installing alarm systems may be required depending on site-specific circumstances.

3.2.2 Buildings and Facilities

The buildings and related facilities required at a hazardous waste landfill include: an administration building, weigh scale, roads, laboratory, personnel wash-up area, vehicle wash, equipment maintenance building, and security system. Site facilities should include: a water supply, sewage disposal, a power source, telephone services, and a vehicle fueling depot. The administration building should provide office space for the site manager and administrative staff and be capable of serving as a reception area for visitors to the site. It should also house the laboratory, personnel wash-up/locker area, lunch room, scale house and other appropriate functions.

The laboratory should be capable of providing rapid verification checks on the physical and chemical nature of the materials to be landfilled. If a chemical solidification/stabilization/fixation process is installed as part of the landfill, then the capabilities of the laboratory can be expanded to include testwork relating to the operation and quality control of that process. Wastes generated by the laboratory should be treated as hazardous wastes unless proven otherwise.

The personnel wash-up facility should include segregated "dirty" and "clean" areas separated by a mandatory shower area. In this fashion, workers' clothing that is potentially contaminated will be kept segregated from street clothing. This would minimize the risk of transporting contaminants from the site inadvertently. Laundry facilities can be provided for workers' clothing and other protective apparel. Shower water and spent laundry water should be segregated and treated as a hazardous waste unless proven otherwise.

The lunch room should be designed to provide a clean environment for workers, administrative staff and visitors eating in the active area of the site. For workers entering from the active area of the site, the eating area should be accessed through the segregated wash-up area.

A weigh scale and scale house should be provided to weigh full and empty vehicles entering and leaving the site for inventory purposes. In addition, a vehicle wash facility should be provided to decontaminate vehicles that have been working in the active areas of the landfill site. Washwater from this facility should be treated as a hazardous waste unless proven otherwise. As well, an equipment maintenance building should be provided to service and repair the vehicles and other equipment used on the site.

The roadways at the site should be designed for easy turning and manoeuvering by constructing them with reasonably shallow gradients. Road surfaces and design load capacities should be compatible with the degree of use intended, particularly in

inclement weather. In this regard, it may be desirable to install paved roads on routes that will be used continuously over the life of the site. This will assist in dust control and provide an all-weather surface for frequently-used routes.

Provision should be made to ensure materials from contaminated or potentially contaminated areas on site are not transported inadvertently from the site by "tire-tracking" or by some other means with vehicles that have been in direct contact with hazardous waste areas. This can be done by one of two methods:

- provision of a transfer point on the landfill site at which vehicles entering the site would off-load their cargo. This cargo would then be picked up and taken to the landfill by vehicles and equipment dedicated exclusively to working in the contaminated areas of the site, or
- provision of a vehicle wash station at which all vehicles leaving the site would be washed thoroughly. The washwater would be treated as a hazardous waste unless proven otherwise.

The selection of a preferred method of transportation will depend upon economics but should also be chosen to be consistent with vehicle management practices used at other hazardous waste facilities that may be on the same site. These may include a physical/chemical/biological treatment plant or a thermal destruction facility.

Guideline 3-6:

The buildings and facilities at a hazardous waste landfill site should include an administration building housing offices, a lunchroom, a laboratory, and a segregated "dirty" and "clean" personnel wash up area. Other facilities which should be provided include a weigh scale, vehicle wash facility and maintenance building.

Guideline 3-7:

Provision should be made to prevent contaminated or potentially contaminated materials from being inadvertently transported from the site by means of "tire-tracking".

Guideline 3-8:

Any contaminated or potentially contaminated liquid wastes generated by activities at the hazardous waste landfill such as worker shower and laundry water, or contaminated vehicle washwater, should be segregated and managed as a hazardous waste unless proven otherwise.

3.2.3 Stormwater Management

Proper stormwater management is a very important consideration in the design and construction of a hazardous waste landfill. Appropriate precautions should be taken to prevent surface water from entering the active areas of the landfill site. Likewise, run-off from such areas should be collected separately, analyzed and if necessary, treated and disposed of as a hazardous waste.

Precipitation falling directly on the open working areas of the landfill that result in a contaminated run-off stream can be avoided by providing a cover for the active area under which work can proceed regardless of weather conditions.

Guideline 3-9:

Run-on should be directed away from active hazardous waste landfills. All reasonable means should be taken to avoid run-off from active portions of a hazardous waste landfill site. If such run-off occurs, it should be considered to be potentially contaminated, checked for quality and, if appropriate, managed as a hazardous waste.

3.2.4 Alternative Landfill Concepts

There are a variety of concepts for the design and construction of the waste cells which are the final repositories for hazardous wastes in a hazardous waste landfill. Figure 3 illustrates, in simplified schematic form, three alternative landfill concepts as described by the Ontario Waste Management Corporation. These concepts are distinguished as follows (M.M. Dillon, 1986):

- **Above-ground** - places the solidified material entirely above the ground surface;
- **Shallow Entombed** - places all of the solidified material below the base of the weathered zone; the top surface of the landfill cover will be approximately at the original ground surface level; and
- **Conventional** - places the solidified material both above and below the ground surface.

Depending on the characteristics of the available site, one landfill method may be more appropriate then another. Each case must be assessed on its own merits with due consideration to such factors as:

- topography,
- soil stratigraphy and permeability,
- water table elevation and gradient,
- climate,
- availability of suitable borrow materials, and
- the extent to which the escape of contaminants are to be controlled.

If it is desirable to maintain the existing topography of the site after completion and closure of the landfill, then the shallow entombed concept might be appropriate. Long-term maintenance is minimized as well with selection of the shallow entombed concept. Alternatively, if it is important to contain waste material above the water table, then the above-ground or conventional landfilling concepts might provide an advantage. However, if the wastes must be placed under the weathered zone to avoid freeze/thaw cycles or possible erosion, the shallow entombed concept would be more appropriate. If there is a shortage of borrow materials to use in constructing the landfill, then either the shallow entombed or the conventional concept might be appropriate as the excavated materials could be used in constructing and completing the landfill.

Guideline 3-10:

The choice of which landfill concept to implement (above-ground, shallow entombed, or conventional) should depend on a detailed consideration of site-specific physical and environmental conditions. Selection of the preferred concept should be made with due consideration of the integrity of the landfill and the extent to which the escape of contaminants from the landfill are to be controlled.

3.2.5 Alternative Landfill Development Methods

There are three general methods for developing a landfill. Each method can be adapted to any one of the three landfill concepts discussed in the preceding subsection. The three landfill development methods are:

- **Cell Development Method** - in which discrete cells are constructed for depositing waste. Each cell is opened, filled, and closed as a unit during a period of weeks or months. This may be a relatively short time frame compared to the life of the overall landfill site. Cells will tend to be relatively square in plan view with length to width ratios approximately equal to 1:1.

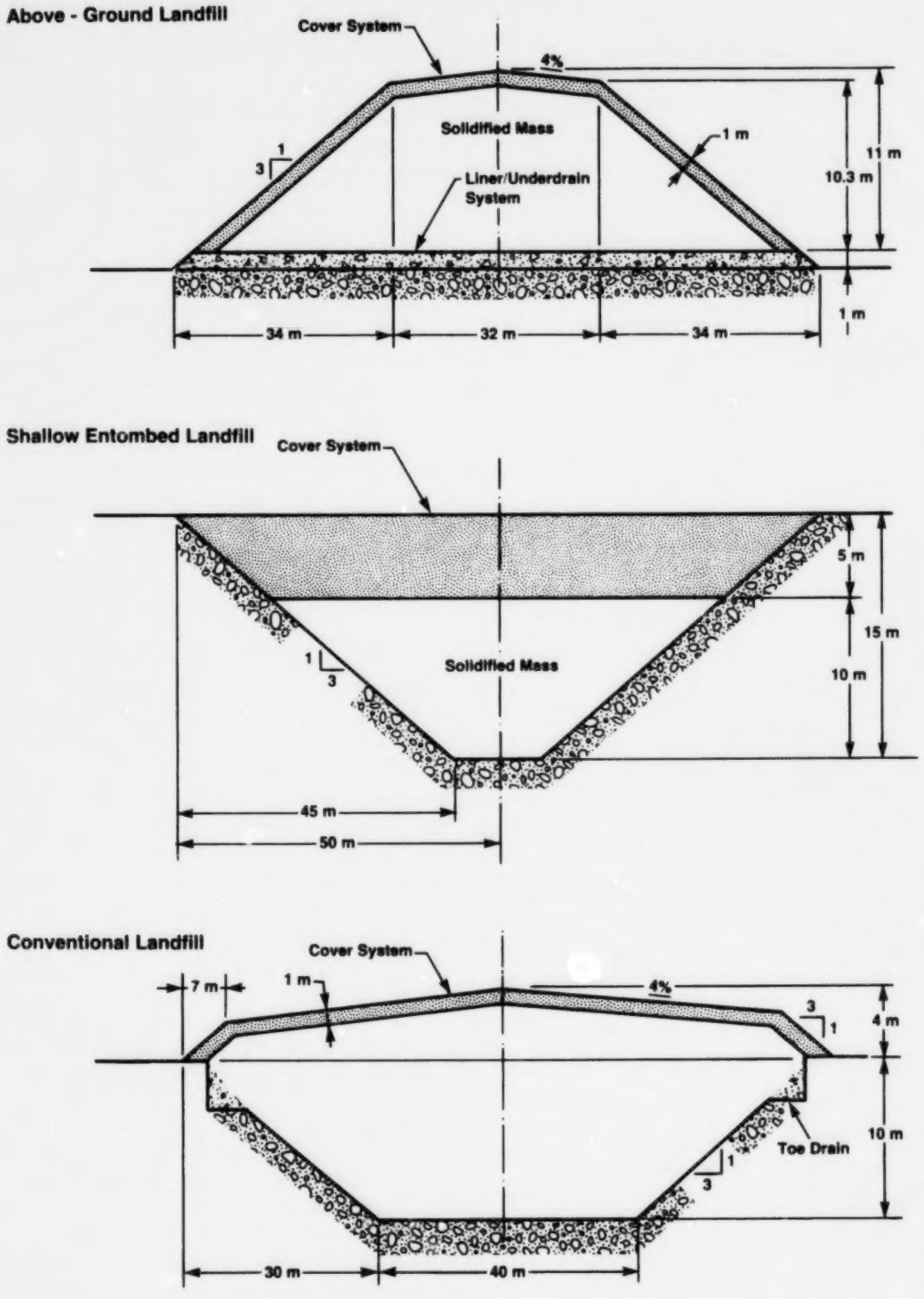


Figure 3 **Landfill Concepts (source: M.M. Dillon, 1986)**

- **Trench Development Method** - in which the cell is extended such that the length to width ratio is substantially greater than 1:1. Unlike a discreet cell, the trench is developed continuously with opening, placing and covering activities advancing in unison as the waste is placed in the trench. A trench is operated over a longer period of time than a cell - from months to years. The length of the trench is constrained by the overall dimensions of the landfill site.

- **Area Development Method** - is a method in which the landfill is developed over the full area available on the site. Similar to the trench method, the landfill operation is continuous with the opening, placing and covering of waste advancing steadily. The area is developed in this fashion over the full life of the landfill site.

In descending order, the area, trench and cell development methods offer the most efficient utilization of available space on the site, all other things being equal. Nevertheless depending on project-specific circumstances, there may be justification to choose one method over another. For example, unique circumstances such as: relatively small waste quantities, seasonal constraints due to harsh weather conditions, the need to provide a cover over the open working face, site configuration and other reasons, may be sufficient to justify using the discrete cell method.

Guideline 3-11:

The choice of which landfill development method (cell, trench or area) to employ should be made in light of site and project-specific factors. In general, the discrete cell method is more suited for the landfilling of smaller waste quantities, whereas the trench or area development methods are more suited to larger waste quantities.

3.2.6 Geotechnical Engineering Considerations

The design of a hazardous waste landfill facility must include consideration of geotechnical engineering principles for the construction of dykes, cut slopes, landfill cells, roadways, and drainage structures.

The strength of both *in situ* and engineered soils should be assessed using appropriate laboratory and *in situ* testing techniques. With a proper knowledge of groundwater flow conditions, and appropriate stability analysis techniques, safety factors for cut slopes and embankment slopes can be determined. Interior cell slopes may be governed by liner design considerations but a minimum safety factor of 1.4 is recommended for all slope designs as noted in the Canadian Foundation Engineering Manual (Canadian Geotechnical Society, 1985). Alternatively, an ultimate limit state analysis can be undertaken using the appropriate factors as recommended in the same reference.

Settlement and heave of net loaded and unloaded areas should also be considered because they can cause stress on, and hence affect the performance of, liner materials and leachate collection systems. In addition, the impact of a liner on the soil moisture regime with respect to net infiltration or evapotranspiration should be examined. In analyzing the stress state of the soil, the bulk unit weight of the hazardous wastes in the landfill should be estimated. This should be based on a knowledge of the landfill components and the method of placement.

Guideline 3-12:

Appropriate geotechnical engineering principles should be applied to those aspects of the hazardous waste landfill facility involving the construction of dykes, cut slopes, landfill cells, roadways, and drainage structures.

3.3 Natural Attenuation Concept

3.3.1 Premises

The natural attenuation approach to hazardous waste landfilling is based on the following premises:

1) Landfilled hazardous wastes will present a threat to the environment for hundreds or thousands of years.

2) Natural site features of soils and geology, and groundwater conditions can provide a very high level of protection for health and the environment. Under these conditions design features can fully utilize these site advantages and long-term care commitments are reduced.

3) The long-term integrity of engineered control measures such as flexible membrane liners, leachate collection systems and sophisticated cover designs has not been proven.

3.3.2 Siting

Sites suitable for the natural attenuation approach consist of areas where no water resources are present that can be adversely affected. Areas where water resources are naturally protected by sound geological formations are also suitable. The natural attenuation approach is also appropriate where the types of wastes placed in the landfill can be controlled so that any leachate produced will be adequately attenuated by the environment.

Proponents for natural attenuation landfills must emphasize the need for a thorough hydrogeological assessment of the landfill site. This assessment must predict the long-term environmental effect of the landfill on the ground-and/or surface water resources and address the results of any abatement measures to reduce adverse effects. The assessment must also investigate the applicability of contingency measures and monitoring plans.

3.3.3 Leachate Control

All containment structures exposed over long periods of time to the weather and various chemicals absorb water. Waste exposed to this water produces leachates. A natural attenuation landfill in a humid climate that relies on clay deposits for environmental protection is expected to accumulate water over the long term. This water and resulting leachate will eventually reach an equilibrium elevation above the base of the waste. Leachate that is produced in the landfill is normally not recovered. Its movement is controlled by the attenuation capacity of the natural environment at the site.

3.3.4 Monitoring

Monitoring is particularly important because it is through long-term monitoring, which may continue for more than one hundred years, that data are gathered to verify the hydrogeologic assessment and permit the final closure of the site.

3.3.5 Long-term Care

The guarantee of long-term care, until the site can be finally decommissioned, is a particularly difficult and complex problem. In the case of natural attenuation landfills, long-term care must include the post-closure costs of facility insurance, site maintenance, contingency plans and monitoring. Depending on site conditions this post-closure period could well exceed 100 years. One of the advantages of the natural attenuation approach is that activities such as leachate collection and treatment are not required, or are required for a limited period only and, therefore, the costs of long-term care are minimized.

3.3.6 Compensating Features

Where adequate natural conditions do not exist, compensating features are required.

The natural attenuation approach will accommodate the incorporation of sophisticated technology and "engineering" into landfill designs. This procedure reduces contaminant discharge to levels that can be accommodated by the natural attenuation capacity of the surrounding environment. For example, it may be necessary to reduce the concentration of a particular contaminant in the leachate by pretreatment of the waste or to reduce the amount of infiltration and leachate production by modifying the cover design. It may also be feasible to incorporate some type of accelerated leaching or in-place treatment system into the design to reduce the strength of the leachate during the first few decades after site closure.

The natural attenuation approach will accommodate the use of flexible membrane liners and leachate collection facilities as added protection in a naturally protective environment, provided these facilities do not interfere with site monitoring.

3.3.7 Examples of Natural Attenuation Landfills

The natural attenuation approach is illustrated by the designs of the Tricil Ltd. landfill and the proposed Ontario Waste Management Corporation landfill in Ontario. These landfill designs allow for a very slow, continuous discharge of contamination from a hazardous waste landfill over a period of hundreds and thousands of years. The sites are designed so that the impact of this contaminant discharge on the receiving ground- or surface water is not significant.

Figure 3 provides an illustration of the "shallow, entombed landfill" concept proposed by the Ontario Waste Management Corporation which is used at the Tricil landfill in southwestern Ontario. A description of the physical characteristics at the Tricil site* follows.

The clay deposits in which the Tricil landfill is placed are approximately 43-m thick and have an average hydraulic conductivity of 3.6×10^{-9} cm/s. Approximately 25 m of this clay separate the base of the waste from the underlying aquifer. Contaminants will move through this clay primarily by diffusion rather than advection. Based on data from older parts of the landfill, it was estimated that it will be 2000 years before contaminants from these wastes reach the underlying aquifer and approximately 10 000 years before this contamination reaches its maximum (acceptable) level. The critical contaminant in this plume is chloride. Contaminants that would not be adequately attenuated by natural processes which could present a potential problem, are not to be landfilled.

The wastes in the landfill are given a final cover of 6 to 7 m of compacted clay. The top of the landfill is finished to a relatively level surface. Infiltration through the cover into the waste after closure is anticipated to be between 0.3 and 3 cm per year. Once leachate production begins, it will require several thousand years for an appreciable amount of contaminants in the waste to move to the underlying aquifer. No flexible membrane liner was planned at Tricil because (a) its service life was felt to be insignificant compared to the time of contaminant travel to the underlying aquifer, and (b) calculations indicated that the environmental impact of the site without a liner will be negligible. No leachate collection system was installed at Tricil either because other provisions (surface water collection) were made for dealing with leachate production from direct precipitation into the site while it was in operation.

The site design proposed by OWMC is for a shallow entombment landfill similar to that of Tricil except for the incorporation of a leachate collection system. This leachate collection system is intended to control water

---

* Information supplied by R. Szudy of Tricil Ltd.

from precipitation that may enter into the operating site. It is also used for monitoring leachate quality in the short term; perhaps thirty years after site closure. It is not intended to serve a long-term function.

3.4 Engineered Containment Concept

3.4.1 Overview of Liner Systems and Leachate Control Concepts

A variety of complete systems for landfill liners and leachate removal have been designed to protect the environment surrounding the landfill site. The topic of landfill liner systems and leachate control concepts has been the subject of considerable debate and as yet, no uniform consensus has emerged on what the preferred approach should be. Regardless of the approach taken, there should be some provisions for a quality control program to ensure that the materials and construction methods used for a landfill site meet the specifications of the approach selected. Examples of various approaches that have been used are described in the following text.

- **United States Environmental Protection Agency Requirements**: In 1984, the EPA mandated under Hazardous and Solid Waste Amendments that hazardous waste landfills be lined with a double liner. Two alternate versions of this were allowed, one using a flexible membrane inner liner and a compacted low permeability soil outer liner, and the other using flexible membrane liners for both the inner and outer liners. Schematic diagrams illustrating these two alternates are presented in Figures 4 and 5, respectively. Figure 6 illustrates a more detailed profile of the Alternate 2 composite, double-liner system.

- **Hazardous Waste Landfill - Midland, Michigan:** A hazardous waste landfill constructed in 1985 in Midland, Michigan, under the Michigan Hazardous Waste Management Act is reported (Cadwallader, 1987) to have the following liner system:

  - a synthetic flexible membrane liner (100 mil high-density polyethylene with leachate collection system-sand layer),
  - a clay layer - 1.5 m thick,
  - a sand layer (for leak detection), and
  - a clay layer 1 m thick on the bottom.

- **Secure Hazardous Waste Landfill - Swan Hills, Alberta:** A secure landfill with a cover over the active cell was constructed in 1986 at the Alberta Special Waste Management Corporation's Swan Hills facility. The following components were placed beneath the landfilled wastes to contain any leachate seeping out of the material (Richardson, 1986):

  - a leachate collection system above liner (synthetic drainage mat),
  - a flexible membrane liner of high density polyethylene,
  - a leak detection and collection system below liner (synthetic drainage mat), and
  - a clay liner.

- **Secure Hazardous Waste Impermeable Cell - LaSalle, Quebec:** In 1988, the municipality of LaSalle, on the outskirts of Montreal, initiated the last phase of the decontamination of the land where the former Lasalle Coke plant was located. This plant, which transformed coal into coke and synthetic natural gases, had operated from 1920 to 1977. The company's land was highly contaminated as the result of spills and the disposal of waste on the plant site. In 1988, the municipality of LaSalle began building a cell to contain some 600 000 m^3 of contaminated soil and waste on the site of

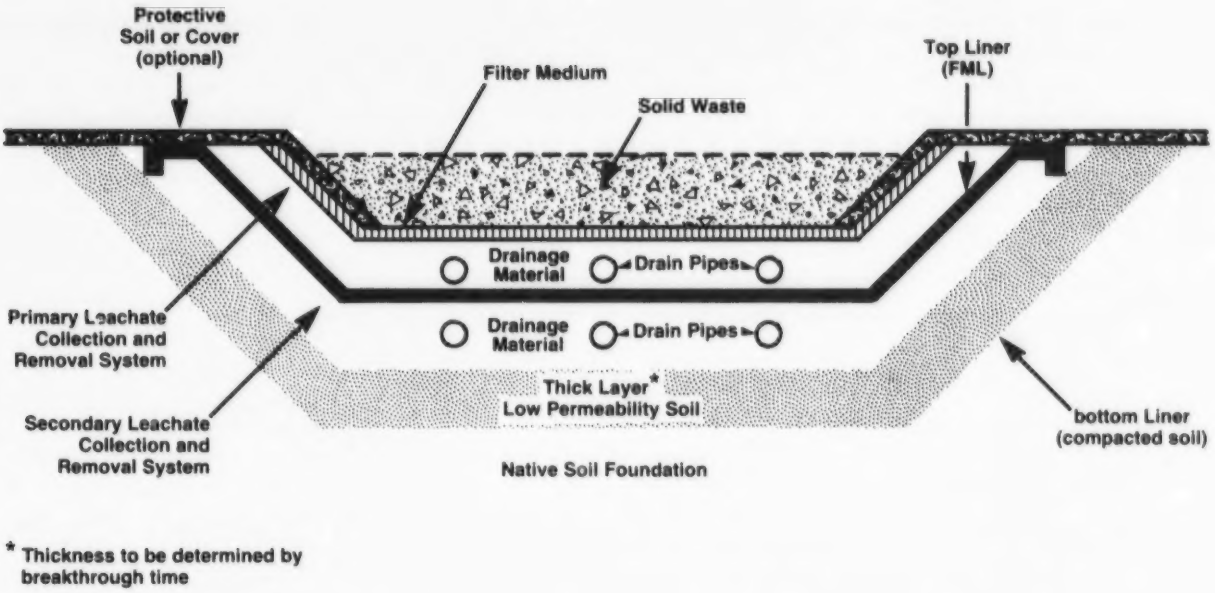


Figure 4 **Schematic Diagram of an EPA Double Liner System for a Hazardous Waste Landfill - Alternate 1**
(Source: McCoy and Associates, 1985)

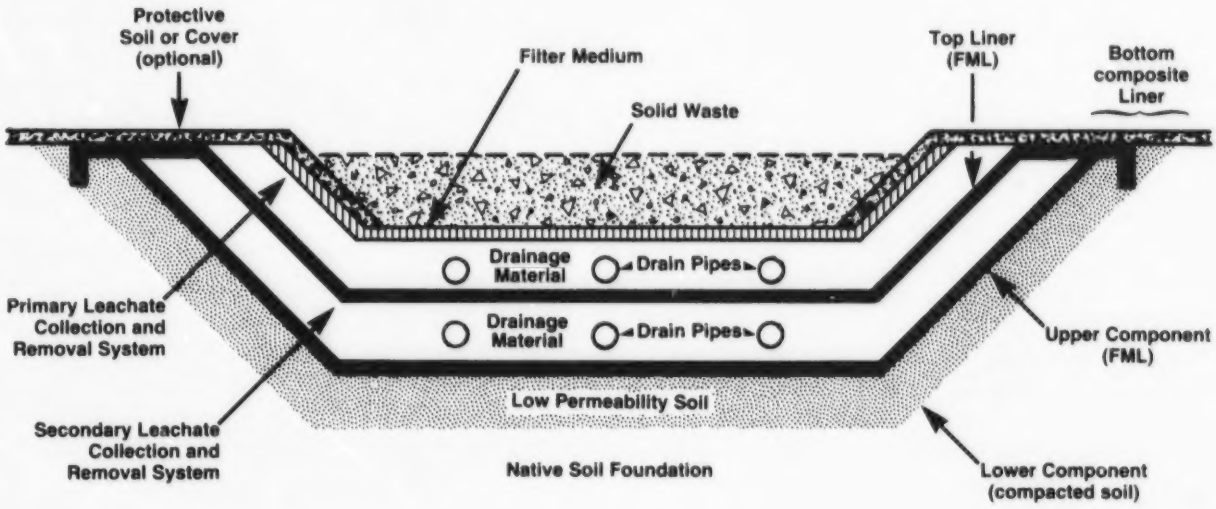
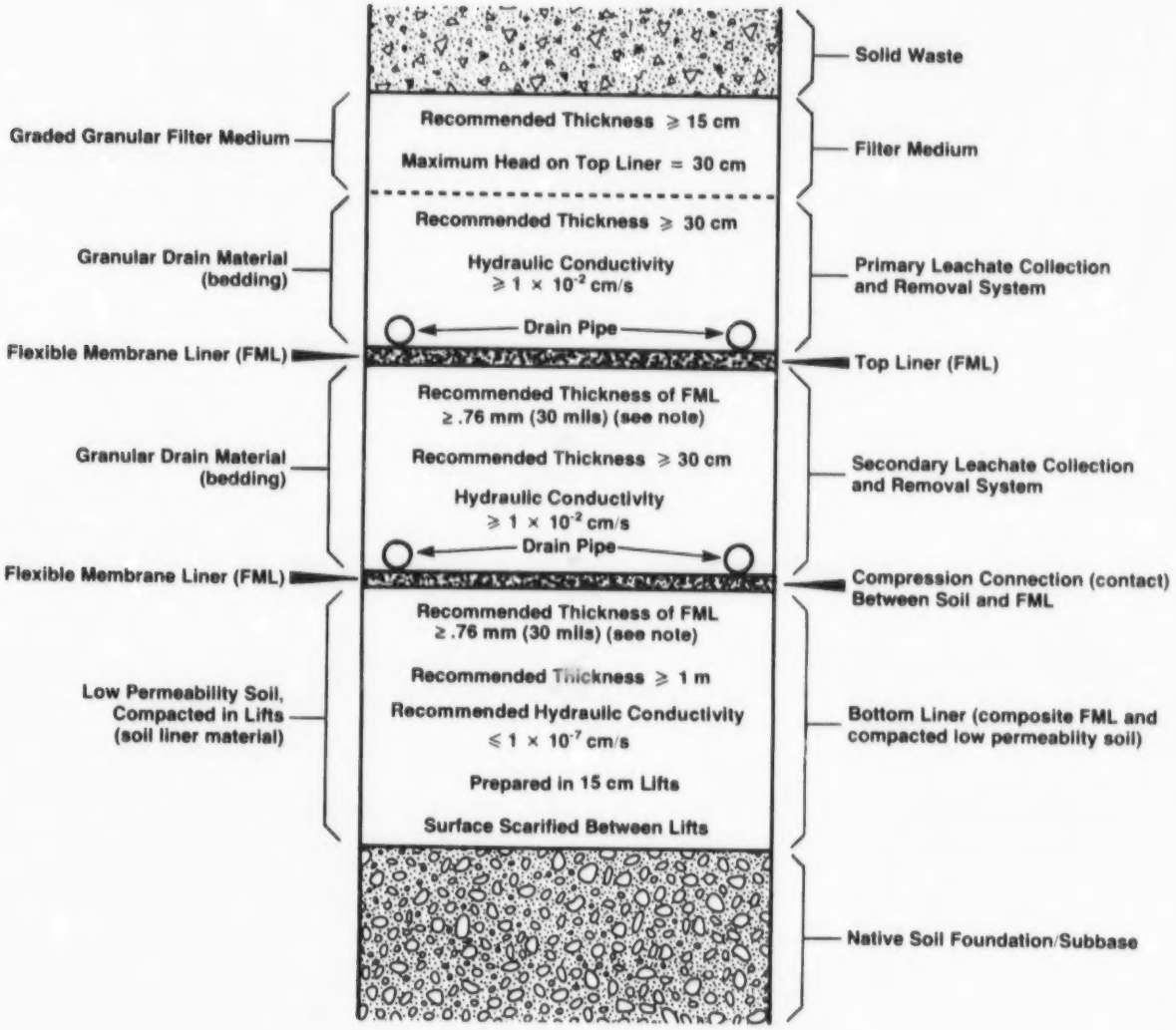


Figure 5 **Schematic Diagram of an EPA Double Liner System for a Hazardous Waste Landfill - Alternate 2**
(Source: McCoy and Associates, 1985)

MATERIALS | DIMENSIONS AND SPECIFICATIONS | NOMENCLATURE


Solid Waste
Graded Granular Filter Medium
Recommended Thickness ≥ 15 cm
Maximum Head on Top Liner = 30 cm
Filter Medium
Granular Drain Material (bedding)
Recommended Thickness ≥ 30 cm
Hydraulic Conductivity ≥ 1 × 10⁻² cm/s
Primary Leachate Collection and Removal System
Drain Pipe
Flexible Membrane Liner (FML)
Top Liner (FML)
Recommended Thickness of FML ≥ .76 mm (30 mils) (see note)
Granular Drain Material (bedding)
Recommended Thickness ≥ 30 cm
Hydraulic Conductivity ≥ 1 × 10⁻² cm/s
Secondary Leachate Collection and Removal System
Drain Pipe
Flexible Membrane Liner (FML)
Compression Connection (contact) Between Soil and FML
Recommended Thickness of FML ≥ .76 mm (30 mils) (see note)
Low Permeability Soil, Compacted in Lifts (soil liner material)
Recommended Thickness ≥ 1 m
Recommended Hydraulic Conductivity ≤ 1 × 10⁻⁷ cm/s
Bottom Liner (composite FML and compacted low permeability soil)
Prepared in 15 cm Lifts
Surface Scarified Between Lifts
Native Soil Foundation/Subbase

Note: FML thickness ≥ 1.14 mm (45 mils) is recommended if the liner is not covered within three months

1 mil = (0.001 in.) = 25.4 μm
100 mil = (0.1 in.) = 2.54 mm

Figure 6 **Schematic Profile of an EPA Composite Double Liner System for a Hazardous Waste Landfill**
(Source: McCoy and Associates, 1985)

the former plant. This cell was designed and built in accordance with the concept of the secure landfill cell by using a double-liner system to render the sides and bottom of the cell impermeable. It was also designed for the collection of leachate and the detection and collection of any liquid between the two geomembranes (Figures 7, 9, and 10).

With a secure landfill cell design, it is possible to drain the contaminated materials that have been landfilled by means of a leachate collection system, thereby minimizing the risk of contaminant migration outside the cell. The leachate collection system at LaSalle overlies the primary geomembrane (HDPE, 2.0 mm) which retains the contaminants inside the cell. Underlying the primary liner is a leak detection and collection system. This system detects and collects any liquid that infiltrates the system. Below it is a second geomembrane (HDPE, 1.0 mm) which constitutes the second impermeable barrier of the secure cell. Lining the bottom of the cell is a layer of clay till with a minimum thickness of 12 m and a mean permeability coefficient of 4×10^{-6} cm/s.

The cell cover consists of three layers, each of which has a distinct purpose (Figure 8). The first layer just above the waste is an impermeable layer, consisting of a geomembrane (HDPE, 1.5 mm) overlying 60 cm of compacted clay. This layer is designed to prevent the infiltration of precipitation. Above the impermeable layer is a 60-cm drainage layer designed to promote rapid drainage of rainwater. The top layer is composed of 30 cm of vegetation which is designed to promote the regrowth of vegetation over the landfill. The two top layers protect the impermeable layer from the effects of the freeze/thaw cycle.

3.4.2 Liner Materials

Many different types of liner materials have been used, or studied for use in landfills. These materials include:

Flexible Membrane Liners

- high density polyethylene (HDPE),
- polyvinyl chloride (PVC),
- butyl rubber,
- neoprene, and
- other polyethylenes (e.g., chlorinated, chlorosulphonated).

Considerations for flexible membrane liners should include:

- compatibility with the waste to be contained and the leachate that may be generated,
- resistance to weathering (e.g., ultraviolet radiation),
- resistance to physical damage,
- resistance to rodents and microbes,
- retention of desirable properties at various temperatures,
- efficiency of jointing and seaming,
- quality assurance/quality control during both manufacturing and placing,
- need for a 0.5- to 1.0-m thick layer of granular material to be placed over the flexible membrane is to protect it during placement of wastes during operation of the landfill, and
- the performance and service life of the liner.

When compared to the numerous other synthetic membrane liner materials, HDPE is presently the material of choice. High density polyethylene exhibits good tensile strength and elongation properties, high tear and puncture resistance, good low temperature brittleness properties, and excellent resistance to attack by a wide variety of chemicals.

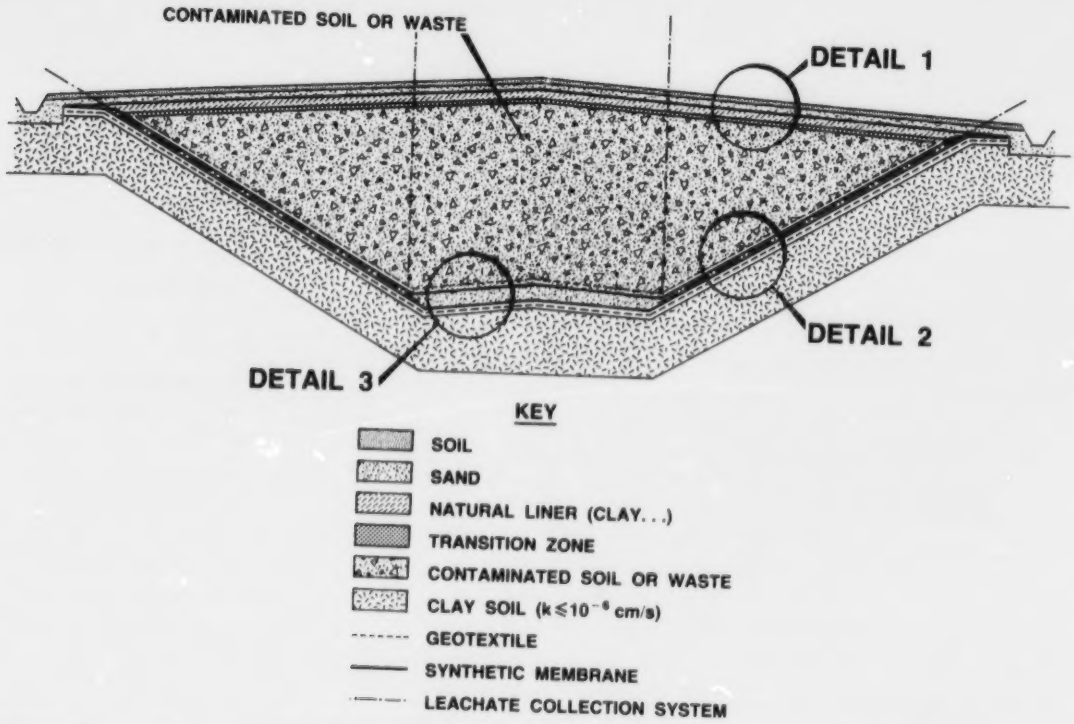


Figure 7 **Cross-section of Impermeable Hazardous Waste Cell (Maximum Security Type, LaSalle, Quebec)**

DETAIL 1

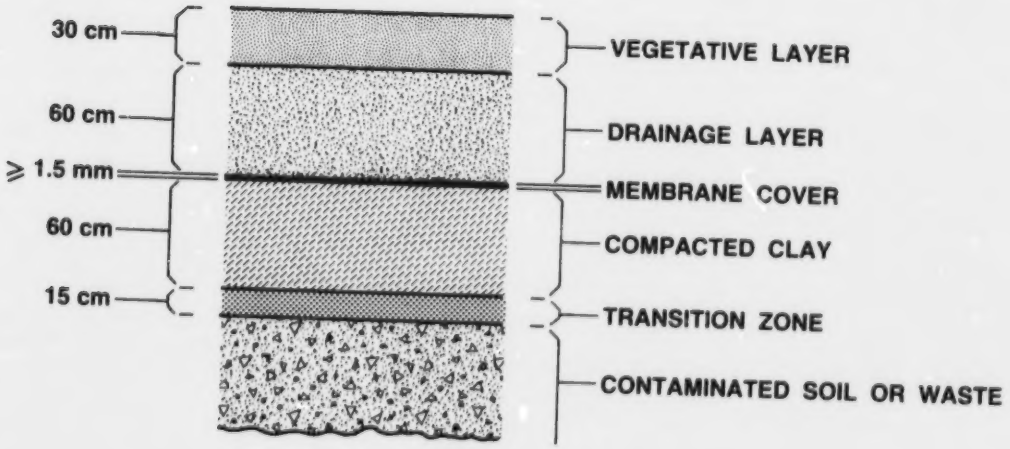


Figure 8 **Cross-section of Cell Cover for Impermeable Hazardous Waste Cell (Maximum Security Type, LaSalle, Quebec)**

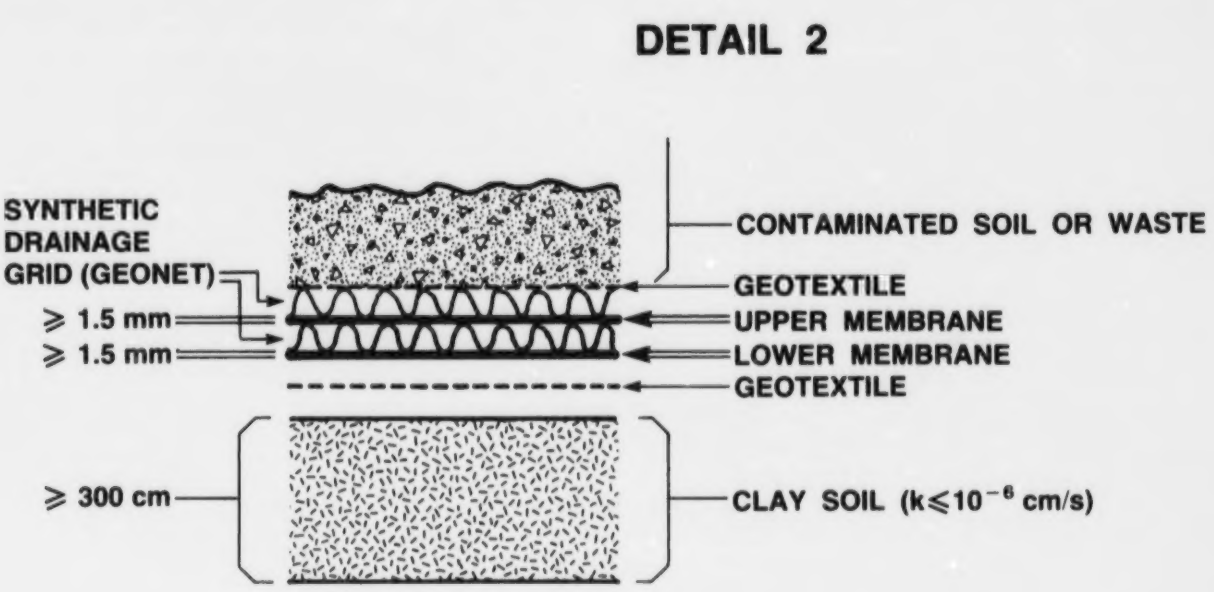


Figure 9 Cross-section of Cell Side in Impermeable Hazardous Waste Cell (Maximum Security Type, LaSalle, Quebec)

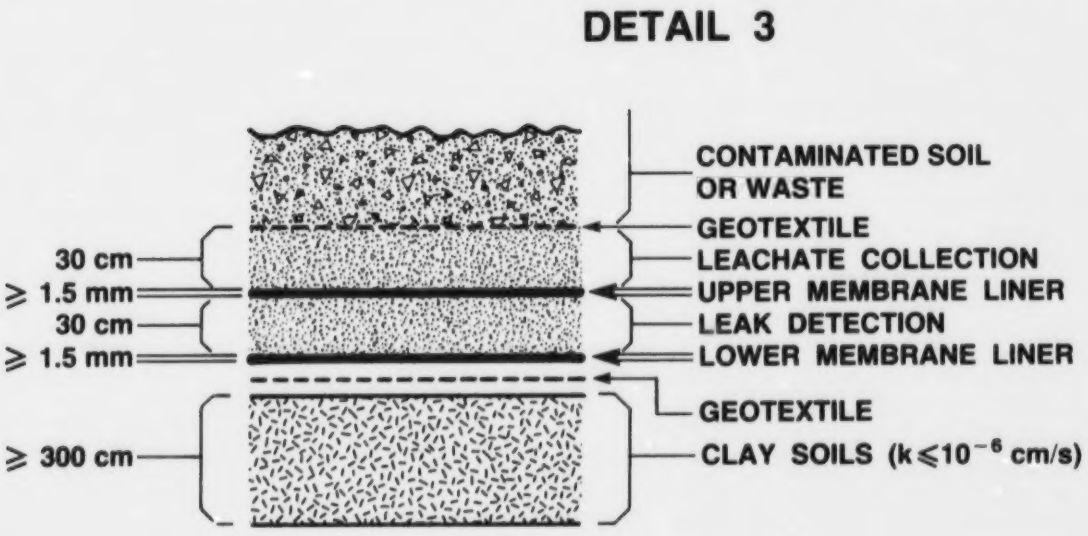


Figure 10 Cross-section of Cell Bottom in Impermeable Hazardous Waste Cell (Maximum Security Type, LaSalle, Quebec)

Soil Liners

Historically, soils with a high clay content have served as liner material in numerous applications. Soil liners are placed on the sides and bottom of a landfill and compacted in layers according to specific requirements. However, the interaction between soil and a variety of chemicals is complex and variable. Thus, the compatibility of soil liners with several types of hazardous wastes is uncertain. Laboratory studies in the early 1980's indicated that concentrated organic liquids could increase the hydraulic conductivities of soils from 100 to 1000 times. Regardless of how representative these tests were of prototype conditions, the EPA subsequently abandoned soil liners in favour of flexible membrane liners (FMLs). This decision by the EPA to mandate FMLs has been challenged by others (Reades and Chart, 1986) for some applications. The Environmental Protection Agency currently favours composite liners consisting of clay and a synthetic material. Considerations for soil liners should include:

- the most effective moisture content for compaction (a "wet condition" of the optimum liner is preferred),
- the type of compaction (kneading type preferred, e.g., sheepsfoot roller over smooth roller),
- the final hydraulic conductivity achieved, and
- the quality assurance/quality control during placement.

Other Liner Materials

Other than flexible membrane liners and clay soils, the following types of liners have been used:

- bentonite and bentonite mixtures,
- soil-cement, and
- sprayed-on material (e.g., asphalt, asphalt in cement, granite).

While these other liners may be considered, they have not found wide application in the hazardous waste management field.

Guideline 3-13:

The specification of a preferred liner material, natural and/or synthetic, will depend on site-specific considerations and shall be based on demonstrated compatibility with the hazardous wastes to be landfilled. Liner material will also be chosen on the basis of its resistance to deterioration/failure due to climatic changes and stresses associated with liner installation and landfill operation.

3.4.3 Leachate Control

Leachate normally is collected above the liner material and conveyed by a network of perforated pipes to sumps or riser pipes for surface containment and disposal. The pipes are placed in a layer of granular materials to allow for percolation of the leachate into the pipes. The thickness of the granular layer typically varies from 0.5 to 1.0 m.

Some considerations for leachate collection systems are:

- the type of pipe material selected (should be resistant to chemical attack by the leachate, and
- the hydraulic design of the system should include factors to limit leachate hydraulic heads above the collection system to acceptable limits. Hydraulic design will cover the size and spacing of the pipe network and determine the type of granular material surrounding the pipes. Hydraulic design should account for precipitation that may occur prior to cover installation.

As an alternative to a pipe collection system, synthetic drainage grids (geonets) and synthetic drainage mats (geotextiles) have been used. These provide a layer of voids or "conduits" for the conveyance of liquids. They can be particularly appropriate on side

slopes. Drainage grids and mats may also be used below liners for leak detection and as a secondary means of leachate removal.

The characteristics of leachate from a new hazardous waste landfill are relatively unpredictable and there is a paucity of background data on this subject. Sampling and analysis at a specific site will determine leachate characteristics. In general, leachate from a hazardous waste landfill should be classified as hazardous waste. Treatment of the leachate can be quite costly and complicated. Therefore, every effort should be made to reduce the amount of leachate to be collected and treated. Rather than construct a leachate treatment facility for relatively small quantities of leachate on the landfill site, the leachate could be hauled to a hazardous waste treatment plant for processing.

Guideline 3-14:

A leachate monitoring, collection and removal system should be installed beneath an "engineered containment" hazardous waste landfill in order to control contaminant migration from the site. Furthermore, any leachate collected from a hazardous waste landfill should be classified as hazardous waste and be managed accordingly unless the waste material is proven not to be hazardous.

3.4.4 Engineered Cover

An engineered cover for a hazardous waste landfill is used for the following purposes:

- to provide a separation between potentially harmful contaminants and the surrounding environment,
- to control surface water infiltration,
- to sustain vegetation growth and provide an aesthetically-pleasing finished appearance, and
- to fulfill engineering functions such as gas control, surface run off management, erosion control and structural integrity.

An important function of the cover is to control infiltration into a landfill thereby preventing an unacceptable buildup of leachate over the bottom liner. In the extreme case, uncontrolled infiltration could allow the waste cell or the landfill to fill with leachate which would then overflow onto the ground surface. It should be noted that, as is the case with liners and leachate collection systems, the long-term performance of engineered covers has yet to be demonstrated.

The Canadian National Research Council's Task Force on Geotechnical Waste Disposal (1983) points out, "the comparison between covers and bottom liners should be based on equalization of flows and not on the basis of equal permeability." Equalization of flows between covers and bottom liners will depend on factors such as relative heads and liner thickness. This approach is considered more desirable because it accounts for local conditions such as rainfall, evaporation and the magnitude of storm events.

A major governing factor in the design of a low permeability zone in the cover is frost and weathering protection. Accordingly, both the EPA and Proctor and Redfern (January, 1985) state that the impermeable layer should be completely beneath the average depth of frost penetration for the area. Although factors such as snow cover may be taken into account, this will require a substantial top layer to protect the low permeability zone.

Subsidence of the cover over the cells is another important consideration. The potential for subsidence will be a function of waste placement procedures, materials used, depth of the cells, and settlements. The thickness, elasticity and elongation of any flexible membrane used as a cover will have to be considered in light of the potential for subsidence to occur. The cover design should also take into account potential exposure,

slope stability and construction disturbance. The surface of the final cover layer should be graded to discharge run-off away from the operating site. The surface should then be planted with grass to enhance evapotranspiration and protect against erosion.

A typical "engineered containment" cover system normally incorporates the following design features:

- a top layer of soil that would accommodate shallow root vegetation native to the area and encourage run-off without erosion,
- a second drainage layer constructed of porous free-draining material to accommodate major sustained storm events and to discourage root penetration in the low permeability zone, and
- a third layer which functions as a barrier to surface water infiltration.

Guideline 3-15:

A final cover system should be installed over each landfill cell with the objective of isolating the wastes, controlling infiltration and providing appropriate erosion protection for the site.

Guideline 3-16:

The barrier layer of the cover system should be integrated securely into the landfill liner system at the perimeter of the landfill cells. In addition, the cover system should be of sufficient thickness to minimize any stresses due to freeze/thaw cycles.

Guideline 3-17:

The cover and bottom liner of the landfill should be designed such that no buildup of fluid occurs in a landfill cell.

3.4.5 Gas Venting

The potential for gas buildup under a landfill cover must be addressed. Gas may be generated in landfilled wastes due to the decomposition of any organic material in the wastes. While it is recommended in Section 2.0 of this guideline document that the placement of organic materials in hazardous waste landfills be minimized, gas evolution could result from volatile chemical wastes inadvertently placed in the landfill. The nature and variability of hazardous wastes makes prediction of gas generation uncertain. Gas may be produced in certain areas of the fill and not in others.

Design measures such as a gas collection layer placed under the impermeable cap liner and the provision of vents should be considered. In the design and construction of a landfill, it would be prudent to allow for the controlled collection and release of gas by a network of pipes in gravel-filled trenches or a similar network system. However, these elements can be dispensed with if little or no gas production is anticipated.

Depending on the nature of the gas released, some form of gas treatment may be desirable. Incineration could be employed if the gas is rich in methane and/or volatile hydrocarbons. Other gas treatments involve wet scrubbing if the gas has a significant hydrogen sulphide content, or carbon absorption if relatively small amounts of volatile hydrocarbons are present in the gas.

Guideline 3-18:

The potential for gas production from the disposed waste should be determined and an appropriate system for gas collection, treatment and release should be provided.

Section 4

Operation and Monitoring

4.1 Overview

The successful implementation of a landfill for the disposal of hazardous wastes hinges on strict control over operating and monitoring procedures. These procedures should complement the general design philosophy of the landfill and also provide for proper closure and post-closure care requirements.

4.2 Administrative Procedures

All operations at the landfill site should be guided by the procedures detailed in an operating manual prepared specifically for the facility. This manual should be comprehensive in scope and, as a minimum, focus on the following topics:

- a description of design intent, cell construction details, the overall landfill development plan, and site closure plan,
- a clear identification of the chain of authority, organizational structure, job descriptions and job responsibilities for all personnel,
- an itemization of mandatory regulatory reporting requirements,
- an itemization of internal written reporting requirements and record keeping,
- a description of health and environmental monitoring programs and related reporting requirements,
- a description of the routine landfill operational procedures including laboratory procedures,
- a description of personnel health and safety precautions and procedures,
- a description of site security protocols, and
- list of authorities to notify in case of mishap.

The operating manual should be the primary information source document for essentially all aspects of site operations and should be available to all personnel for convenient reference. It should be revised and updated on a regular basis as new procedures are developed to cope with changing market, environmental or regulatory conditions.

A waste materials inventory control and record keeping system should be developed and rigorously followed at the site. Items to be addressed in this system should include:

- manifest checking and filing of manifests for incoming waste deliveries,
- weigh scale and laboratory analysis records of incoming deliveries for internal inventory control (and for customer billing purposes as required), and
- "as-built" drawings of the completed landfill cells which include recorded dates of placement, operating staff responsible, and types and sources of wastes placed therein.

A comprehensive vehicle and equipment maintenance manual should be prepared for all mobile and stationary equipment on the site. In addition to operating and maintenance instructions, the manual should describe what equipment decontamination procedures and personnel protection measures are required for maintenance work. If maintenance is conducted on equipment used in the active areas of the hazardous waste site, any spent materials such as soaps and solvents are to be

classified as hazardous waste. This should be clearly stated in the maintenance manual. The manual should be used as a basic reference document for operating and maintaining the equipment at the site.

Guideline 4-1:

A comprehensive facility-specific operating manual should be prepared for a hazardous waste landfill. This manual should be reviewed by all staff, and used as the primary reference document for day-to-day operation of the landfill.

Guideline 4-2:

A comprehensive waste materials inventory control and record-keeping system should be established for the landfill site and rigorously adhered to by all operating personnel.

Guideline 4-3:

A comprehensive vehicle and equipment maintenance manual should be prepared for all mobile and stationary equipment on the site and be used as a basic equipment reference manual. The maintenance manual should include equipment decontamination and personnel protection measures.

4.3 Placement of Wastes

The placement of hazardous wastes in the landfill should follow the requirements set forth in the landfill development plan described in Section 4.0 of this document. This would give due consideration to the preferred landfill concept, cell design including a leachate control system, cell development, capping and closure requirements. Placement of wastes must also give due consideration to the segregation of incompatible materials in order to minimize the risk of dangers such as explosions, fires, and the evolution of toxic gases.

Since the infiltration of direct precipitation and surface water run-on into a landfill contributes to the generation of contaminated leachate, efforts should be made to control the intrusion of water into the waste cells. A cover can be installed over the active face of the landfill to help prevent the infiltration of direct precipitation. The other advantage of this approach is that it enables work to continue during inclement weather. Any water run-off from the active areas of a hazardous waste landfill should be collected and treated as a hazardous waste.

As the wastes are placed in lifts, they should be compacted by a mechanical rolling device (sheepsfoot, vibratory, etc.) as necessary to minimize subsidence of the completed landfill structure. This requirement may not be appropriate when dealing with solidified wastes.

To prevent the transport of contaminated or potentially contaminated materials from the site, either one of the two measures outlined below should be adopted regarding vehicles that come into direct contact with the active areas of the landfill site:

- off-loading wastes delivered to the site by "off-site" vehicles with subsequent handling of the wastes by "on-site" vehicles exclusively dedicated to working in the active area of the landfill, or
- washing all contaminated and potentially contaminated vehicles before they leave the site. The washwater would be treated as a hazardous waste unless proven otherwise.

Guideline 4-4:

Direct precipitation and surface water run-on to the active areas of the landfill site should be controlled. Any water run-off from the active areas of a hazardous waste landfill should be collected and treated as a hazardous waste unless proven otherwise.

Guideline 4-5:

Care should be taken when operating equipment to ensure that the integrity of the landfill liner and leachate control system is not breached.

Guideline 4-6:

Care should be taken in equipment operation and maintenance to ensure that contaminated materials are not inadvertently "tracked" from the active areas of the landfill site. In this regard, equipment washwater and spent cleaning solutions should be collected separately and treated as a hazardous waste unless proven otherwise.

4.4 Emergency Procedures

An emergency procedures plan for dealing with all realistically foreseeable mishaps at the landfill site which could endanger human health or the environment should be prepared and updated on a regular basis. Examples of such incidents include fires, explosions, accidental spills of contaminants in nonactive areas, and the generation of unanticipated contaminated run-off and/or leachate.

The emergency procedures plan would include the following components for dealing with each type of mishap:

- immediate response measures,
- names, addresses and contact numbers for all persons qualified to act as an emergency coordinator,
- names, addresses and contact numbers of individuals, agencies, or organizations who can provide additional assistance,
- evacuation plans for facility personnel and nearby residents should the need arise,
- appropriate medium and long-term remedial measures,
- inventory and location of emergency equipment to be kept on hand at the facility, and
- incident reporting format and procedures.

Instruction on the emergency procedures plan should be an integral part of the training program for all employees at the landfill. The inventory of equipment necessary for immediate response to the mishaps outlined in the emergency procedures plan should be kept readily available at the landfill site. Equipment for medium and long-term response actions need not be immediately available on site. However, the emergency procedures plan should note specific locations nearby where it can be obtained on short notice. In this regard, the plan should be prepared in consultation with community emergency response authorities in the vicinity of the landfill site. Copies of the plan should be distributed to all nearby agencies such as police and fire departments, provincial and municipal emergency response teams which might be called upon, and local hospitals.

Guideline 4-7:

An emergency procedures plan should be prepared for responding to all realistically foreseeable mishaps which could occur on the landfill site. The plan should be prepared in consultation with provincial and nearby community emergency response authorities.

Guideline 4-8:

The emergency procedures plan should be reviewed and amended on a regular basis to reflect changes in personnel, technology, equipment and/or response procedures.

4.5 Personnel Programs

All personnel at the landfill site should successfully complete a mandatory training program appropriate to their job functions. Following the initial indoctrination program, there should be regular "refresher" programs

designed to reinforce established procedures and introduce new procedures. Personnel records should be maintained to document the nature and timing of training completed by each employee.

The training programs should be given by qualified and experienced instructors. As a minimum, the following topics are recommended:

- landfill concepts and day-to-day landfill operating procedures,
- equipment operating instructions and safe practices,
- emergency procedures plan indoctrination,
- wearing of protective clothing and equipment,
- appropriate personal hygiene measures regarding matters such as washup, eating, and laundry, and
- first-aid rescue measures.

All personnel on the site should be given thorough premedical examinations as well as frequent periodic examinations throughout the duration of their employment on the site. If there is reason to suspect that a worker has been unduly exposed to contamination, then a more intensive health monitoring program focussing on the specific toxicological manifestations of the contaminant(s) in question may be warranted. The medical examination program should be directed by a qualified medical practitioner.

Guideline 4-9:

All personnel at the landfill site should be given a comprehensive training program and be subject to thorough medical examinations before and during their period of employment at the site.

4.6 *Environmental Monitoring Programs*

4.6.1 Overview

As indicated previously, a landfill engineered for hazardous wastes requires strong expertise in design and construction to control the escape of contaminants to the environment. Regardless of the level of this effort, all landfills should be monitored primarily for the following reasons:

- to check on the adequacy of its performance, and
- to provide an "early warning" system so that any necessary remedial work can be carried out expeditiously.

Prior to the establishment of any landfill facility, it is imperative that an environmental baseline profile be prepared for the proposed site and immediate surrounding area. This profile should serve as the reference point for all subsequent monitoring efforts.

Monitoring must be carried out during the operational life of the landfill, and during the post-closure period. The degree of monitoring will be determined by the actual findings and their potential adverse consequences. For example, a landfill site which displays only a small but constant amount of leachate leakage over several post-closure years may receive intermittent monitoring for the remainder of the post-closure period. By contrast, a landfill exhibiting a substantial leak should be extensively monitored.

By way of example, monitoring typically includes the following areas:

- site security,
- physical movement,
- surface water quality,
- groundwater quality,
- air emissions,

- contaminant control facilities, and
- general inspection.

A set of monitoring standards should be established in advance of the landfill commissioning which will indicate when the site has failed to meet acceptable conditions. Corrective actions can then be taken. Consideration could also be given to the establishment of a second set of standards that would allow for decreasing the monitoring frequency or decommissioning the monitoring and/or contaminant control systems.

4.6.2 Physical Movement

Landfills should be monitored for subsidence or a lowering of cover elevations due to the collapse or consolidation of the wastes. Elevations monitored should include the cover over the filled area as well as other points around the site. Proper subsidence monitoring requires secure benchmarks, or similar monuments, judiciously placed at the site with their elevations determined by precision levelling from a benchmark well away from the site.

4.6.3 Leachate

Leachate collected at a landfill underdrain system should be monitored for:

- the amount being produced, and
- its physical and chemical characteristics.

The data should be analyzed to determine any trends. The particular leachate characteristics will also influence its ultimate fate in the environment. Leachates from a hazardous waste landfill should be considered a hazardous waste, until proven otherwise, and disposed of accordingly.

4.6.4 Leakage

If a leak detection system (secondary leachate collection system) has been installed as part of the landfill liner system, any liquid appearing in it should be monitored for flow and physical, chemical and toxicological characteristics to determine if it is an actual leachate leak or whether the liquid is from another source.

4.6.5 Groundwater

Due to the potential for severe adverse effects on groundwater resources, groundwater monitoring is a very important component of performance monitoring at a hazardous waste disposal landfill. A comprehensive groundwater monitoring program will provide reliable data on the effect that the landfill has on the groundwater quality of the site.

To be effective, the monitoring program must be based on a solid understanding of the groundwater flow system in the area. Hydrology studies conducted during the site exploration phase of the landfill project would provide this knowledge. In overview, a groundwater quality monitoring program should consist of the following components:

- background water level monitoring for at least one year before operation of a landfill,
- initial detailed sampling of groundwater constituents prior to landfill construction,
- details of and frequency of ongoing water level monitoring and sample analysis program during landfill construction and operation,
- long-term post-closure monitoring, and
- periodic analysis to compare the results of monitoring wells to the background water quality in order to assess the environmental impact of the landfill.

Additional information on subsurface contaminant migration may be gathered by collecting soil-core samples from certain areas and conducting analyses for the occurrence of contaminants. Various types of lysimeters also may be used to monitor pore-liquids in the unsaturated zone.

4.6.6 Air Emissions

Air emissions during landfill operations will include dust from earth moving, excavation, placing of wastes and placing of the cover. These emissions should be sampled by placing dustfall samplers and/or high volume ambient air samplers at various locations around the perimeter of the site. If there is no nearby weather station that records wind speed and direction, such equipment should be installed at the landfill site so that correlations between air quality measurements, wind direction and speed can be made.

During the later stages of the operational period as well as during the post-closure period, any air monitoring concerns should focus on the emissions from the vent pipes. The amount and type of gas discharged will vary considerably from one site to another. Even the emission levels between vents will vary since the generation of gas depends on the amount and types of wastes present. Air samples may be collected from either the vent pipes or from the ambient air. Portable gas probes may be used. In extreme cases of concern, gas detectors may be installed.

The sampling and analysis program for air emissions should include the following:

- dustfall,
- suspended particulate matter (from high-volume samplers),
- total reduced sulphur compounds (ambient and from vent pipes),
- total hydrocarbons (ambient and from vent pipes), and
- other appropriate contaminants.

4.6.7 General Inspection

Visual inspection should be carried out to address such items as: security (condition of fences, signs, gates), growth of cover vegetation, condition of surface water drainage channels, weathering, and destructive burrowing by animals.

Guideline 4-10:

Prior to the establishment of a hazardous waste landfill facility, the proponent should prepare an environmental baseline profile of the proposed site and immediate surrounding area. This profile will serve as the reference point for subsequent monitoring efforts.

Guideline 4-11:

The owner or operator of a hazardous waste landfill facility should be required to implement an environmental monitoring program for both operational and post-closure periods. This program would apply to physical movement of the landfill, leachate leakage, groundwater and air emissions. Furthermore, comprehensive historical records should be maintained of all monitoring data collected for the pre-operational, operational and post-closure stages of the site.

Guideline 4-12:

Prior to commencing operation, consideration should be given to the establishment of monitoring standards. In the event that monitoring results fail to meet these standards, a remedial action plan would be implemented as called for in the emergency procedures plan.

Section 5

Closure and Post-closure

5.1 Overview

When a hazardous waste landfill site has come to the end of its useful life, it must be closed. Closure procedures may also be applied to portions of a large site where filling operations are completed.

Planning for closure and post-closure care of the landfill site should be undertaken during the initial planning stages for the overall project. By integrating closure considerations into the landfill design at the outset, the landfill development plan will be compatible with proper decommissioning and long-term care requirements when the life of the site has been fulfilled.

Guideline 5-1:

Closure and post-closure care plans for a hazardous waste landfill site should be prepared as part of the initial planning and design phase for the overall facility. In addition, they should be updated if they are in any way affected by changes in facility design or operating procedures during the active life of the landfill.

5.2 Closure

Specific closure procedures should ensure that the long-term integrity and security of the site is maintained. Of prime importance is the protection of human health and the environment. In addition, the closure program should be directed toward minimizing the need for maintenance of the site after closure. The potential costs for long-term maintenance can be considerable and is an important factor to take into account when selecting a landfill concept.

Mobile and stationary equipment used in the active portions of the site should be decontaminated and the contaminated washwaster residuals should be treated as a hazardous waste.

Guideline 5-2:

The owner or operator of a hazardous waste landfill site should be required to close the facility in a manner that:

- **minimizes the need for further maintenance, and**
- **controls the post-closure escape of hazardous contaminants to the groundwater, surface water and atmosphere to the proper extent necessary to protect human health and the environment.**

Guideline 5-3:

When closure is completed, all equipment and facilities used at the site, with the exception of monitoring facilities and equipment, should be decontaminated or disposed of in an appropriate manner.

5.3 Post-closure Care

The subsequent use of the landfill site should be identified and appropriate land use controls implemented to ensure that the designated use is not violated. As a guide, long-term uses should be selected so that the security of the wastes deposited in the site is not breached. This would exclude uses involving significant construction activities such as buildings, roads, and pipelines. However, it could allow for less intensive land uses such as passive forms of recreation. Access to the site could also be sealed off for an indefinite period.

The preferred option will depend on site-specific conditions including the results of the on-going monitoring program. If subsidence, gas venting, and/or leachate generation becomes a significant problem, then it may be desirable to seal off the site indefinitely until the situation is stabilized.

The monitoring systems should be maintained and operated on a regular basis during the post-closure period to check for possible problems. Particular attention should be paid to the groundwater monitoring system. In addition, periodic visual inspections of the site should be made to observe the integrity of the landfill cover and surface water drainage systems. These inspections would also ensure that the authorized use of the site is not being violated. Remedial measures should be undertaken as soon as potential problems are identified.

Guideline 5-4:

Land use restrictions for the completed site should be defined and maintained indefinitely.

Guideline 5-5:

The post-closure care plan should provide a description of activities which will be conducted after final closure of the site and the frequency of these activities. As a minimum, these activities should include:

- **maintaining the function and integrity of the final cover,**
- **maintaining and operating the leachate and gas collection, treatment systems if installed,**
- **protection and maintenance of survey benchmarks, and**
- **control of access to the site in accordance with its approved post-closure use.**

5.4 Preservation of Records

A central repository should be established in which "as-built" drawings and relevant operating records of the landfill are maintained for an indefinite period for future reference. This repository should also include the cumulative records of the monitoring programs during both the operational and post-closure phases of the site. Once the landfill site is closed, the records should be placed in the custody of the provincial regulatory agency responsible for regulating the post-closure activities on the site.

Guideline 5-6:

A central repository for "as-built" drawings and other operational records should be established. The results of on-going monitoring programs should also be compiled at the repository and maintained indefinitely by the provincial regulatory agency responsible for regulating the post-closure activities of the site. Consideration should be given to entrenching the long-term maintenance of records in the form of legislation.

5.5 Liability

If during operation or after closure, a problem is detected during the on-going monitoring of the landfill site, then remedial measures will be required to repair the problem. Depending upon the type of measures required, considerable costs could be incurred either as a one-time capital expense or as a continuing operational and maintenance cost. In order to meet these costs, some form of contingency financing should be provided as part of the initial funding for the project. Alternative approaches to provide such financing include:

- purchase of liability insurance either by the owner/operator of the site or by the government,

- posting of a bond or other form of guarantee by the owner/operator of the site, and
- institution of a levy in proportion to the quantity of waste placed in the landfill to create a remedial measures fund.

The amount of contingency financing that should be provided will depend on a number of factors including:

- size and configuration of the completed landfill site,
- type and properties of the wastes deposited therein, and
- characteristics of the environment in the immediate vicinity of the landfill in relation to the cost of performing remedial measures.

Guideline 5-7:

Prior to commencing operation, some form of contingency financing should be provided in the event that the integrity of the landfill is breached and repairs are required either during its active life or following closure. The amount of financing required will depend on the size of the landfill, the types of wastes placed therein and pertinent site-specific factors. As a reference for establishing a contingency fund, a current record should be kept of the costs of remedial measures at hazardous waste landfill sites across North America.

Guideline 5-8:

To ensure the continuity of post-closure care for the hazardous landfill site and to eliminate the potential for another party to unknowingly acquire it, the site should be legally registered on the appropriate deed or land title prior to commencing operation.

References

Cadwallader, M.W., "Hazardous Waste Landfill Uses Unique Three-Layer Liner", *World Wastes* (February, 1987).

Canada. *Transportation of Dangerous Goods Act,* R.S., C.T-19, Sections 2, 21 and 24 (1985).

Canadian Geotechnical Society, *Canadian Foundation Engineering Manual,* 2nd Edition, 456 p., Vancouver: The Society (1985).

M.M. Dillon Limited, "OWMC Treatment Facility Process Area Report Engineered Landfill", Toronto, Ontario (November, 1986).

McCoy and Associates, *The Hazardous Waste Consultant,* Vol. 3, Issue 4, published by McCoy and Associates, Sakewood, CO, U.S.A. (July/August, 1985).

National Research Council of Canada, Committee on Geotechnical Research, Task Force on Waste Disposed, "Geotechnical Aspects of Waste Disposal", Technical Memorandum Series No. 135 (1983).

Proctor and Redfern Group (The), "The Assessment of the Problems Posed by Hazardous Wastes in Landfills and the Identification of Regulatory Control Options", Control Options Report, The Proctor and Redfern Group, Toronto (January, 1985).

Reades, D. and Chart, T., "Landfill Design", *Proceedings, First Annual Workshop on Waste Management,* University of Toronto (March 17-20, 1986).

Richardson, J.S., "Swan Hills Special Waste Treatment Facility Design and Operational Plan", presented at: *Hazmat Waste 86 Hazardous Materials Management Conference and Exhibition,* West Long Beach, CA (Dec. 3 to 5, 1986).

U.S. Environmental Protection Agency, "Paint Filter Liquids Testing Method 9095", U.S. Federal Register 50, 18370 (April, 1985).

Bibliography

Alberta Environment, "Interim Report on Site Selection Program and Public Participation for the Integrated Hazardous Waste Management System", Edmonton: Hazardous Waste Implementation Program (October,1981).

Alberta Environment, "Hazardous Waste Management in Alberta", Edmonton: Hazardous Waste Management Committee (undated).

Anderson, D., "Does Landfill Leachate Make Clay Liners More Permeable?", *Civil Engineering* (September, 1982).

Anfuso, G. and P. Cheremisinoff, "Landfills for Hazardous Waste Disposal", *Plant Engineering* (September 1, 1983).

Anonymous, "Budget Office Publishes Road Map of Future Hazardous Waste Regulating Programs", *The Hazardous Waste Consultant ,3*(6): 2.26 - 2.19 (1985a).

Anonymous, "Give Me Anything But a Hazardous Waste Facility", *The Hazardous Waste Consultant, 3*(6): 1.31 - 1.32 (1985b).

Anonymous, "Ontario Zeroes in on a Waste Management Site: Exhaustive Site-Selection Process Described", *The Hazardous Waste Consultant, 3* (6): 2.5 - 2.12 (1985c).

Anonymous, "Criteria for Selecting Off-site TSD Facilities for RCRA and CERCLA Response Actions Specified by EPA", *The Hazardous Waste Consultant, 4*(1): 2.31. (1986a).

Anonymous, "Location Criteria for Siting TSD Facilities May Have Broad Impact", *The Hazardous Waste Consultant, 4* (6): 2.1 - 2.6 (1986b).

Anonymous, "Selecting an Off-site Hazardous Waste Disposal Facility", *The Hazardous Waste Consultant, 4* (6): 3.5 - 3.7 (1986c).

Armour, A., (ed.), "The Not-in-my-backyard Syndrome:" A two-day Symposium on *Public Involvement in Siting Waste Management Facilities*, Toronto: York University, Faculty of Environmental Studies (May 13-14, 1984).

Atkinson, J.M., "Site Selection for Hazardous Waste Management Facility", *Paper presented to Hazardous Waste Management Seminar*, Conference Centre, Ottawa, Ontario (December, 1979).

Bealer, R., K. Martin, and D. Crider, "Sociological Aspects of Siting Facilities for Solid Waste Disposal", Department of Agricultural Economics and Rural Sociology, The Pennsylvania State University, Pennsylvania (1982).

Bellman, H.S., C. Sampson and G.W. Cormick, "Using Mediation When Siting Hazardous Waste Management Facilities: A Handbook". Office of Solid Waste, Washington D.C.: U.S. Environmental Protection Agency (1982).

Beveridge & Diamond, P.C., "Summary and Analysis of the Hazardous and Solid Waste Amendments of 1984", *Number 1, Hazardous Waste and Hazardous Materials*, N. Beecher (ed.) (Spring, 1984).

Boyle, S.B., "An Analysis of Siting New Hazardous Waste Management Facilities Through a Compensation and Incentives Approach", *Discussions in Environmental Health Planning*, Paul Brandford, gen. ed. Ithaca, New York: Cornell University, Department of City and Regional Planning and the Program in Urban and Regional Studies, Environmental Health Training Program (1982).

British Columbia Ministry of Environment, "Special Waste Regulations" (B.C. Reg. 63/88).

Budd, W.W., "A Comparison of Three Risk Assessment Techniques for Evaluating a Hazardous Waste Landfill, *Hazardous Waste and Hazardous Materials", 3* (3): 309 - 320 (1986).

Caffrey, P., D. Martin and R.K. Ham, "Evaluation of Environmental Impact of Landfills", *Journal of the Environmental Engineering Division*: 55 - 69 (1976).

Canada Gazette, Part II, "Transportation of Dangerous Goods Regulations (February 6, 1985).

Cashman, J.R., *Management of Hazardous Waste: Treatment, Storage, Disposal Facilities*, Technomic Publishing, Lancaster, PA (1986).

Centaur Associates Inc., "Siting of Hazardous Waste Management Facilities and Public Opposition Report", SW-809, U.S. EPA, Office of Solid Waste, Washington, D.C. (1979).

Clark-McGlennon Associates, "Negotiating to Protect Your Interests: A Handbook on Siting Acceptable Hazardous Waste Facilities in New England", prepared for New England Regional Commission, Boston, MA (1980a).

Clark-McGlennon Associates, "An Introduction to Facilities for Hazardous Waste Management. A Handbook on Siting Acceptable Hazardous Waste Facilities in New England", prepared for New England Regional Commission, Boston, MA (1980b).

Clark-McGlennon Associates, "Criteria for Evaluating Sites for Hazardous Waste Management. A Handbook on Siting Acceptable Hazardous Waste Facilities in New England", prepared For New England Regional Commission, Boston, MA (1980c).

Clark-McGlennon Associates, "A Decision Guide for Siting Acceptable Hazardous Waste Facilities in New England", prepared for New England Regional Commission, Boston, MA (1980d).

Cleveland, J.A. *et al.*, "Using Computers for Site Selection", *Environmental Science and Technology", 13* (7): 792 - 797 (1979).

Conner, D.M. and A.C. Svendsen, "Overcoming the Barriers to Public Acceptance of Waste Management Facilities", *Proceedings, 8th Canadian Waste Management Conference*, September 3 - 5, 1986, Halifax, Nova Scotia, Ottawa: Supply and Services Canada, p. 1 - 11 (1986).

Cope, C.B., W.H. Fuller and S.L. Willets, *The Scientific Management of Hazardous Wastes*, Cambridge University Press, Cambridge, England (1983).

Cormick G.W., "Environmental Mediation: A Possible Approach to Siting Conflicts in Hazardous Waste Management?", An Outline of Remarks Presented to *Hazardous Waste Management Seminar*, Ottawa, Ontario, December 12, 1979, Office Of Environmental Mediation, Institute for Environmental Studies, University of Alternate Sites, The Company, Edmonton (1979).

Department of the Environment Landfill Practices Review Group, "The Selection of Landfill Sites", Department of the Environment, London, England (1984).

M.M. Dillon Limited, "Alberta Special Waste Treatment Facility, Technical and External Servicing Evaluation of Alternate Sites", The Company, Edmonton (1983a).

M.M. Dillon Limited, "Landfilling of Hazardous Wastes", Report prepared for Waste Management Branch, Environmental Protection Service, Environment Canada (1983b).

M.M. Dillon Limited, "Landfilling of Hazardous Wastes" (Report and Appendices) (April, 1983).

Environment Canada, "Canada's Special Places in the North: An Environment Canada Perspective for the '80s", Ottawa: Supply and Services Canada (1982).

Environment Canada, "6th National Conference on Waste Management in Canada, Speakers' Outlines" Vancouver, (November 7, 8, 9, 1984).

Environment Canada, Environmental Protection Services, Waste Management Branch, "Technical Criteria for Designating Hazardous Wastes in Canada", Environment Canada (May, 1985).

Environment Canada, Industrial Programs Branch, Waste Management Division, "Users' Guide to Hazardous Waste Classification Transportation of Dangerous Goods Regulations", Environment Canada (April, 1986).

Environment Canada, "Proceedings, 8th Canadian Waste Management Conference, September 3 - 5, 1986, Halifax", Ottawa: Supply and Services Canada (1986).

Environment Council of Alberta, "Hazardous Waste Management in Alberta, Report and Recommendations", *The Council*, Edmonton (1980).

Environment, Department of., "The Selection of Landfill Sites. WLR Technical Note Series No. 64", *Landfill Practices Review Group*, Land Waste Division: London, England (undated).

Fields, T. and A. Lindsay, "Landfill Disposal of Hazardous Wastes, a Review of Literature and Known Approaches", U.S. Environmental Protection Agency, Office of Solid Waste Management Programs, Washington, D.C. (September, 1975).

Galegar, J., "Annotated Literature References on Land Treatment of Hazardous Waste", Environmental Research Institute, East Central Oklahoma State University, Ada, Okla: Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency; Springfield, VA: NTIS (distributor) (1984).

Government of Ontario, "Environmental Protection Act, Regulation 309" (General Waste Management) (June, 1985).

Great Lakes Basin Commission Staff, (The), "Earth Sciences Considerations in Siting Secure Hazardous Waste Landfills": *Workshop Results, Analysis and Recommendations*, prepared for United States Geophysical Survey (1981).

Harthill, M. (ed.), *Hazardous Waste Management: In Whose Backyard?* American Association for the Advancement of Science, Westview Press, Boulder, CO (1984).

Hazardous Waste Dialogue Group, Members, "Siting Hazardous Waste Management Facilities: A Handbook", Sponsored by Program For Environmental Dispute Resolution, The Conservation Foundation, Tavemeier, FL, The Conservation Foundation: Chemical Manufacturers Association: National Audubon Society (1983).

Hess, P.J., "Groundwater Use in Canada, 1981", *NHRI Paper No. 28,* IWD Tech. Bull. No. 140, Ottawa: Environment Canada, Inland Waters Directorate, National Hydrology Research Institute (1986).

Institute of Environmental Research Inc., "The Design of Public Consultation Program for Hazardous Waste Facilities", Report prepared for Waste Management Branch, Fisheries and Environment Canada, Toronto (1979).

Jones, D.H. and P.H. Beyer, "Study of Professional Needs in Social and Hazardous Waste Management", *Proceedings, 6th Canadian Waste Management Conference*, Vancouver (1984).

Krawetz, N.M., "Hazardous Waste Management. A Review of Social Concerns and Aspects of Public Involvement", *Staff Report 4*, Edmonton: Alberta Environment, Research Secretariat (1979).

James F. MacLaren Limited, "Interim Report to the Ministry of the Environment for Development of Treatment and/or Disposal Sites for Liquid Industrial Wastes and Hazardous Wastes", Report prepared for Ministry of Environment, Ottawa, Toronto (1979).

Magorian, C., *Public Participation and Hazardous Waste Facility Siting: An Annotated Bibliography*, Philadelphia, PA, Pennsylvania Environmental Research Foundation (1982).

Minnesota Waste Management Board, "Charting a Course. Public Participation in the Siting of Hazardous Waste Facilities", Crystal, MN (1981).

McCoy and Associates, "Membrane Liners, Advances in the State of the Art", *The Hazardous Waste Consultant, Vol. 2*, Issue 5 (Sept/Oct., 1984).

McCoy and Associates, "EPA Takes Steps to Implement HSWA: Massive New Program Foreseen", *The Hazardous Waste Consultant, Vol. 3*, Issue 4 (July/August, 1985).

McCoy and Associates Ltd., "EPA Amends RCRA Interim Status Standards for Land Disposal Facilities", *The Hazardous Waste Consultant, Vol. 3*, Issue 4 (July/August, 1985).

McCoy and Associates, "EPA Proposes Schedule for Land Disposal Bans", *The Hazardous Waste Consultant, Vol.3*, Issue 4 (July/August, 1985).

McCoy and Associates, "Unique Landfill Design Provides Added Groundwater Protection", *The Hazardous Waste Consultant, Vol. 4*, Issue 2 (March/April, 1986).

McCoy and Associates, "Landfill Disposal Restrictions Proposed for "California List" Wastes", *The Hazardous Waste Consultant, Vol. 5*, Issue 2 (March/April, 1987).

McCoy and Associates, "Stricter Rule on Landfilling of Containerized Wastes Proposed", *The Hazardous Waste Consultant, Vol. 5*, Issue 2 (March/April, 1987).

McMahon, R., *et al.*, "Using Compensation and Incentives when Siting Hazardous Waste Management Facilities: A Handbook", Offices of Solid Waste, Washington, D.C., U.S. Environmental Protection Agency (1982).

McQuaid-Cook, J., "Yes In My Backyard - Managing Special Wastes in Alberta", *Proceedings, 8th Canadian Waste Management Conference*, p. 29 -37 (1986).

McQuaid-Cook, J. and K.J. Simpson, "Siting a Fully-Integrated Waste Management Facility", *Journal of the Air Pollution Control Association, 36* (9): 1031 - 1036 (1986).

Montague, P., "Hazardous Waste Landfills: Some Lessons from New Jersey", *Civic Engineering ASCE* (September, 1982).

Morell, D. and C. Magorian, "Siting Hazardous Waste Facilities: Local Opposition and the Myth of Preemption", Cambridge, Mass.: Balinger Publishing (1982).

National Institute for Occupational Safety and Health (NIOSH), "Occupational Safety and Health Guidelines Manual for Hazardous Waste Activities", Publication No. 85-115 (October, 1985).

North Atlantic Treaty Organization, "Disposal of Hazardous Wastes. Recommended Procedures for Hazardous Waste Management", No. 62. Committee on the Challenges of Modern Society.

O'Hare, M., L. Baron and D. Sanderson, *Facility Siting and Public Opposition*, Van Nostrand Reinhold Co., New York (1984).

Ontario Waste Management Corporation, "Phase One Background Study Reports", *The Corporation*, Toronto, Various Publications (1982-83).

Ontario Waste Management Corporation, "Phase Three Interim Background Study Reports", *The Corporation*, Toronto, Various Publications (1983-84).

Ontario Waste Management Corporation, "Site Selection Process, Place 3B" Selection of Candidate Sites", *The Corporation*, Toronto,16 volumes (1984).

Ontario Waste Management Corporation, "Facilities Development Process, Phase 4A Report: The Selection of a Preferred Site", *The Corporation*, Toronto (1985).

Ontario Waste Management Corporation, "Facilities Development Process Phase 4A Report: The Selection of a Preferred Site", Ontario Waste Management Corporation (September, 1985).

Picher, M., "Mediating the Siting of Waste Disposal Facilities - Two Views: The Mediator's Perspective", *Canadian Environmental Mediation Newsletter*, *1*(1): 1-2 (1986).

Redhead, R.J., "Tricil's Sarnia Application, Public Participation: An Exercise in Frustration - Or Was It?", *Proceedings, 8th Canadian Waste Management Conference*, p. 39 - 42 (1986).

Reid Crowther and Partners Ltd., "Remedial Measures for the PCB Spill at Federal Pioneer Limited in Regina", Report prepared for Saskatchewan Environment, Calgary (1980).

Reid Crowther and Partners Ltd., "Hazardous Wastes in Northern and Western Canada, The Need for a Waste Management Strategy", Report prepared for Environment Canada and Others, Calgary, 3 volumes (1980-81).

Scace, R.C., and J.G. Nelson (eds.), "Heritage for Tomorrow, Proceedings of the Canadian Assembly on National Parks and Protected Areas", 5 Volumes, Ottawa: Supply and Services Canada (1986-87).

Schomaker, N.B., "Hazardous Waste Landfill Research, U.S.E.P.A. Program", U.S. Environmental Protection Agency, Land Pollution Control Division, Cincinnatti, OH, (November, 1986).

Scott, M.P., "Strategies for Land Disposal of Hazardous Wastes", paper presented at a meeting of the Northern Eastern District Centre, Newcastle (December 7, 1977).

Selig, Edward, "Institutional Arrangements for Developing Hazardous Waste Facilities in New England", prepared for Clark- McGlennon Associates, Inc., and submitted to New England Regional Commission, Various Papers (1980).

Shrybman, S., "Mediating the Siting of Waste Disposal Facilities - Two Views: A Participant's Perspective," *Canadian Environmental Mediation Newsletter, 1*(1): 2-4 (1986).

Shuckrow, A., A. Pajak and C.J. Touhill, "Management of Hazardous Waste Leachate", U.S. Environmental Protection Agency, Washington, D.C. (September, 1980).

Shuckrow, A., A. Pajak and C.J. Touhill, "Hazardous Waste Leachate Management Manual", Noyes Data Corporation, New Jersey (1982).

Sittig, M., "Landfills Disposal of Hazardous Wastes and Sludges", Noyes Data Corporation, New Jersey (1979).

Stanley Associates Engineering Ltd., "Waste Management in the North: A Discussion Paper", prepared for Northern Environment Directorate, Indian and Northern Affairs, Edmonton (1986).

Tascherau, P.M., "The Status of Ecological Reserves in Canada", Ottawa: The Canadian Council on Ecological Areas (1985).

Task Force on Geotechnical Aspects of Waste Disposal, "Report to NRC Associate Subcommittee on Geotechnical Research" (February, 1982).

U.S. Environmental Protection Agency, 40 CRR Parts 264 and 270, "Hazardous Waste Management System, Groundwater Monitoring, Proposed Rule", *Federal Register, Vol. 51,* No. 142 (July 24, 1986).

U.S. Environmental Protection Agency, "Prohibition on the Placement of Bulk Liquid Hazardous Waste in Landfills: Statutory and Interpretive Guidance", National Technical Information Service, Washington, D.C. (June 11, 1986).

U.S. Environmental Protection Agency, Land Disposal Branch, Office of Solid Waste, "Restrictions on the Placement of Non-hazardous Liquids in Hazardous Waste Landfills", National Technical Information Service, Washington, D.C. (April, 1986).

U.S. Environmental Protection Agency, Office of Solid Waste, "Closure/Post-Closure and Financial Responsibility Requirements. Hazardous Waste Treatment Storage, and Disposal Facilities", U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. (April, 1986).

U. S. Environmental Protection Agency, "Hazardous Waste: Generation of Hazardous Wastes (100 to 1000 Kilograms per Month), On Site Storage, etc; Final Rule", *U.S. Federal Register, 40,* 10146 (March 24, 1986).

U.S. Environmental Protection Agency, "Draft Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units", U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C. (December, 1984).

U.S. Environmental Protection Agency, Office of Solid Waste, "Hazardous Waste Management System: General Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities", U.S. Environmental Protection Agency, Washington, D.C. (July, 1981).

U.S. Environmental Protection Agency, Office of Solid Waste, "Hazardous Waste Management System: General Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities and Hazardous Waste Permit Program", U.S. Environmental

Protection Agency, Office of Solid Waste, Washington, D.C. (July, 1981).

U.S. Environmental Protection Agency, "Standards Applicable to Hazardous Waste Land Disposal Facilities, Proposed and Temporary Interim Final Regulations", *Federal Register, Vol. 46,* No. 30 (February 13, 1981).

U.S. Environmental Protection Agency, "Hazardous Waste Management System, Standards Applicable to Owners and Operators of Treatment, Storage, and Disposal Facilities and Permit Program", *Federal Register, Vol. 46,* No. 24 (Feb. 5, 1981).

U.S. Environmental Protection Agency, "Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities, Interim Final Rule and Proposed Rule", *Federal Register, Vol. 46,* No. 15 (Jan. 23, 1981).

U.S. Environmental Protection Agency, 40 CFR Parts 122, 264, and 265, "Standards Applicable to Owners and Operators of Hazardous Waste Treatment Storage, and Disposal Facilities; Consolidated Permit Regulations", *Federal Register, Vol. 46,* No. 7, pp. 2802 - 2818 (January 12, 1981).

U.S. Environmental Protection Agency, "Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities. General Facility Standards for Location", U.S. Environmental Protection Agency, Washington, D.C. (December, 1980).

U.S. Environmental Protection Agency, Office of Water and Waste Management, "Questions and Answers on Hazardous Waste Regulations" Environmental Protection Agency (November, 1980).

U.S. Environmental Protection Agency, Office of Solid Waste, " Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Groundwater Monitoring", U.S. Environmental Protection Agency, Washington, D.C. (May, 1980).

U.S. Environmental Protection Agency, "Hazardous Waste Management System. Standards Applicable to Generators of Hazardous Waste", *Federal Register, Vol. 45,* No. 98 (May 19, 1980).

U.S. Environmental Protection Agency, "Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities. Interim Status Standards for Landfills", National Technical Information Service, Washington, D.C. (April, 1980).

U.S. Environmental Protection Agency, Office of Solid Waste, " Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities under RCRA, Subtitle C, Section 3004 Interim Status Standards for Closure and Post-Closure Care", U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. (April, 1980).

U.S. Environmental Protection Agency, Office of Solid Waste, "Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities Under RCRA, Subtitle C, Section 3004, Standards for Preparedness and Prevention Standards for Contingency Plan and Emergency Procedures", U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. (April, 1980).

U.S. Environmental Protection Agency, "Criteria for Classification of Solid Waste Disposal Facilities and Practices, Final, Interim Final, and Proposed Regulations", *Federal Register, Vol. 44,* No. 179 (Sept. 13, 1979).

U.S. Environmental Protection Agency, Office of Solid Waste, "Draft Environmental Impact Statement on the Proposed Guideline for the Landfill Disposal of Solid Waste", U.S. Environmental Protection Agency, Washington, D.C. (March, 1979).

Ward, B., and Harris, Christopher, "The 1984 Hazardous and Solid Waste Amendments: A Bold Experiment in Hazardous Waste Management", *Journal of Air Pollution Control Association, Vol. 35,* No. 3 (March, 1985).

Water Management Steering Committee, Working Group V, "The Incorporation of the Reasonable Use Concept into the Groundwater Management Activities of the Ministry of the Environment", Ontario Ministry of the Environment Water Resources Branch (July, 1984).

White, D.C., "EPA Program for Treatment Alternatives for Hazardous Waste", *Journal of the Air Pollution Control Association, Vol. 35,* No. 4 (April, 1985).

Willams, John R. and G.D. Willson, "A Guide to Public Consultation/ Environmental Mediation or "What's in a Blend", *Proceedings, 8th Canadian Waste Management Conference*, p. 43 - 47 (1986).

Zeiss, C., "The Financial and Social Costs of Waste Disposal", M. Sc. Thesis, School of Community and Regional Planning, University of British Columbia, Vancouver (1984).

Zeiss, C. and J. Atwater, "The Impacts of Waste Disposal Facility on Residential Communities: A Perspective for Research Proceedings", *8th Canadian Waste Management Conference*, p. 15-27 (1986).